



Minerals to metals initiative

The impacts and conflicts associated with defunct gold tailings storage facilities in South Africa: A case study of Davidsonville, Central Rand

By

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SYNOPSIS

Gold mining generates large quantities of tailings waste. These tailings can have a significant negative impact on the surrounding environment, with concomitant effects on local ecosystems, as well as on human health and quality of livelihoods. The latter is a concern in the Witwatersrand goldfields of South Africa, where communities are located in close proximity to gold mining operations and/or both current and defunct tailings dumps. This research project was, therefore, aimed at developing a better understanding of the facts, perceptions, concerns, and expectations associated with Witwatersrand gold mine tailings storage facilities, and how these are related. In order to fulfil this aim, a desktop study was conducted which involved a detailed review of published academic literature, company reports, newspaper articles, gold mining magazines, and specialist reports with specific emphasis placed on the Central Rand goldfields of the Witwatersrand Basin. Semi-structured interviews were also conducted with representatives from the community, civil society organisations and independent experts, using the defunct Princess gold tailings dump in Davidsonville Suburb (West of Johannesburg) as a case study.

The literature review of the study has shown that there is environmental pollution (air, water and soil) due to gold tailings dumps in current and historic gold mining areas. These findings were found to be largely consistent with perceptions and concerns of the community members, civil society organisations and subject matter experts. The long-term impacts of this pollution are not only environmental but cause a huge social burden on health and quality of livelihoods. Not only is dust considered a nuisance, particularly in the windy season, but the dust has been proven to contain crystalline silica and radionuclides. The long-term exposure to this dust can lead to skin problems and respiratory illnesses. There is higher exposure of ambient particulate matter (PM₁₀) in areas around tailings even at distances up to 2 km downwind from the tailings dumps. Acid mine drainage, on the other hand, increases metal load in watercourses and soils, ultimately affecting the ecosystems as the metals are toxic to plants. Metal contamination has adverse impacts on animal and human health.

In addition to literature survey, results from the semi-structured interviews revealed that there are conflicts between the communities, government and mining companies, with communities associating their health problems with gold mine tailings. This has led to court cases and gained media attention. The complex relationships between mine waste, the environment, and community health and livelihoods are still not well understood, making it difficult to justify and motivate the implementation of meaningful interventions to mitigate risks associated with gold tailings dumps. To date, little attempt appears to have been made to support community concerns and perceptions

with factual evidence and information. Overall, this study has demonstrated the existence of long-standing issues associated with defunct gold tailings dumps and the communication gap that existing between various stakeholders, i.e. community, government and mining houses. These emphasizes the importance of having adequate remedial actions to prevent further pollution, the need to engage all relevant stakeholders when dealing with gold tailings and implementation of regulatory frameworks associated with gold tailings reclamation and rehabilitation.

DECLARATION

I, Phumzile Cynthia Nwaila, hereby declare that the work on which this dissertation/thesis is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university. This thesis/dissertation has been submitted to the Turnitin module (or equivalent similarity and originality checking software) and I confirm that my supervisor has seen my report and any concerns revealed by such have been resolved with my supervisor.

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ABBREVIATIONS AND ACRONYMS

AMD	Acid Mine Drainage
CER	Centre for Environmental Rights
CSO	Civil Society Organisations
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Management and Tourism
DWS	Department of Water and Sanitation
EIA	Environmental Impact Assessment
EMP	Environmental Management Programme
EMPR	Environmental Management Programme Report
GDP	Gross Domestic Product
ICMM	International Council on Mining and Metals
MMSD	Mining, Minerals and Sustainable Development
MPRDA	Minerals and Petroleum Resources Development Act
NWA	National Water Act
NEMA	National Environmental Management Act
PM	Particulate Matter
SDGs	Sustainable Development Goals
WRC	Water Research Commission
WRI	World Resources Institute
WUL	Water Users Licence

CHAPTER 1

INTRODUCTION

This chapter gives a brief background of gold mining in South Africa, its potential environmental impacts, and the conflicts that are associated with gold mining waste. An overview of what motivated the study and the problem statement is discussed together with the aim and objectives of the study, research questions and project methodology. The project scope and dissertation structure are also outlined.

1.1. Background

South Africa is unique among countries worldwide because of its above-average endowment in a number of mineral deposits, especially gold, platinum group metals, base metals, iron ore, and coal (Frimmel et al., 2005; McCarthy, 2011). These mineral resources, especially gold, have enabled South Africa to contribute to the world economic growth (Rösner and van Schalkwyk, 2000). The Witwatersrand Basin in South Africa is by far the largest single gold-producing province in the world. This basin has produced over 53 000 t of gold over a century of mining (Frimmel et al., 2005). In 2016 alone, South Africa produced 140 t of gold and contributed up to 16 % (Figure 1-1) towards mining gross domestic product (GDP) of R304 billion (CMSA, 2016; USGS, 2017). Gold mining has also contributed to building the South African economy into one of the most developed emerging economies in the African continent (Nite and Steward, 2012; Maseki, 2013). For over 120 years, the mining industry in South Africa has been the driving force behind economic growth and social development, particularly in terms of foreign exchange earnings, employment, and other economic activities. Major infrastructure, recreational facilities, and community developments occurred during peak gold production output, especially in the mid-1970s, making the city of Johannesburg (South Africa) a world-class economic hub (Naicker et al., 2003; Ojelede, 2012). The development of cities was often accompanied by a significant influx of people. As the need for residential areas intensified with time, available open spaces declined; thus, much of the land initially reserved for mining purposes has so far been converted into manufacturing and residential areas. Therefore, not only did mining shape the economy, but it has shaped the socio-political and cultural development of South Africa and is continuing to do so (Smit, 2013).

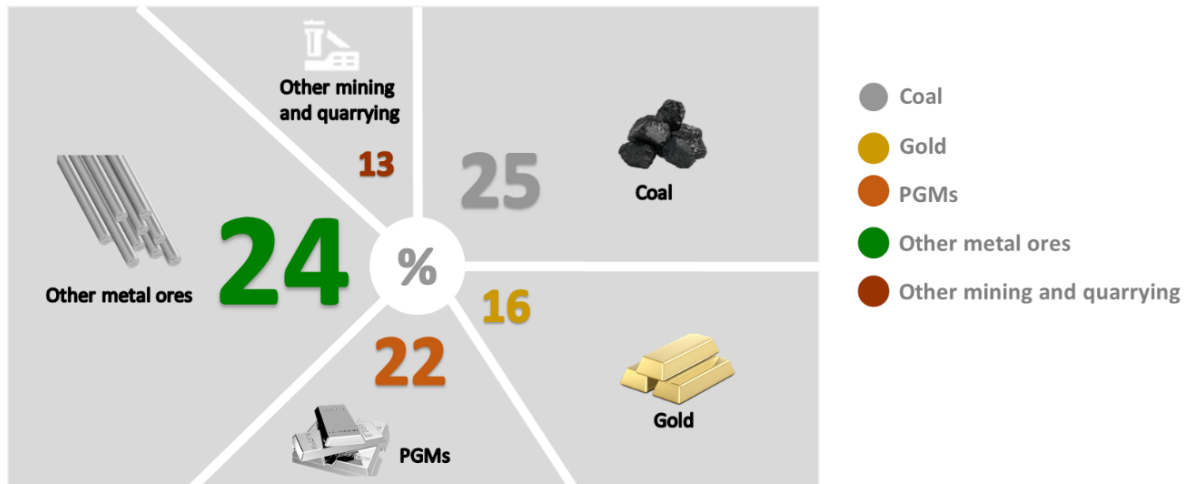


Figure 1- 1: Individual mining commodity contribution in percentages towards mining GDP (After CMSA, 2016).

Regardless of the tremendous socio-economic benefits brought by gold mining, operational production activities associated with gold mining impose a significant and irreversible socio-environmental impact to the surrounding environment and communities (Oelefse, 2008; McCarthy, 2011). A seminal study by McCarthy (2011) has shown that the longer-term impacts of gold mining are far more likely to be severe in South Africa than in other countries because of its exceptional depth of underground gold mines, geographic setting, climate, population distribution, and the scale of mining operations which mimic the large size of gold ore deposits. These impacts are often recognised after mining has ceased to operate (Nkosi, 2016); thus, they affect the sustainable livelihoods of communities and frequently also present a long-term economic burden and loss of valuable resources such as land and freshwater.

In the Gauteng Province, gold mining is responsible for vast tracts of infertile and unproductive landscapes that have been left behind after decommissioning of the mining activities. Tailings Storage Facilities (TSFs) are examples of these unproductive structures that exist in the Johannesburg area as a result of a history of gold mining activities in the Witwatersrand Basin. During mining and gold ore processing, large tonnages of waste are generated, much of which (>95 %) is piled in TSFs, and a minor fraction (<5 %) is used for mining void backfilling. The TSFs were historically designed for the purpose of active ore storage, dormant ore reserve, ore flow control, and waste temporal and permanent disposals. Generally, the gold tailings consist of metals, sulphide compounds, radionuclides, and a variety of inorganic chemicals used during ore treatment. When sulphides, particularly pyrite and compounds are exposed to air and water, they react to form acid, which results in it becoming known as “acid mine drainage (AMD)” (Lenntech, 2004; Wright et al., 2014). The resultant AMD is usually associated with lower water pH, high sulphate

content, and elevated concentrations of a broad spectrum of metals, for example, cobalt, copper, zinc, arsenic, and lead. Although some metals such as zinc are essential for human physiological processes, at higher concentrations, they have harmful effects (Fashola et al., 2016). When metals exceed their natural limits in humans, they lead to adverse health effects such as neurological, cardiovascular, and respiratory ailments, while uranium is associated with kidney damage (Wright et al., 2014).

Some of the underpinning problems in the government's inability to address pollution by AMD in an effective and timely manner have been highlighted in previous reports by Durand (2012) and Naidoo (2017). The primary factor is that most of the gold mines in the Witwatersrand were abandoned or liquidated long before AMD became evident (Naicker et al., 2003). Many of the remaining companies have changed ownership or were amalgamated into larger companies, hindering attempts by the government departments to include these mining companies in the rehabilitation of the impacted areas, as mining companies usually claim to have inherited the AMD problem which already existed before their take-over (Durand, 2012). Another factor is that there has also been very little enforcement of legislation by the government, which is attributed to the close relationship between the gold mines and government. Durand (2012) notes that the close relationship between government and the mines has become even more of a problem in recent years, with numerous conspicuous government officials and their close relatives being directors of mining companies. Historically, there has been a deficiency in the unification of the policy and legislation on mine water management, due to the issue being addressed by four different acts through three different government departments (Adler et al., 2007). In order to deal with the above-mentioned problem, the government has designed a "one environment" system which has its own set of issues.

In the present state, defunct gold tailings deposits in South Africa are spatially intertwined with surrounding communities and associated mine features such as disused shafts and processing plant equipment (Ojelede, 2012). These defunct gold tailings deposits are commonly located next to human formal and informal residential areas. Watkins et al. (2019) estimated that 1.6 million people in Gauteng alone live in settlements close to defunct gold tailings deposits. Many communities located south-west of Johannesburg such as Davidsonville, Soweto, and Riverlea run the risk of being exposed to a variety of harmful elements emanating from the defunct gold tailings deposits (IHRC, 2016; Wright et al., 2014). Certain residential areas in Gauteng Province such as Carletonville, Westonaria, Khutsong, Kagiso, and Randfontein fall within areas that are now classified as having the highest risk of radiation exposure emanating from the defunct gold tailings deposits (DMR, 2008). A recent study by the Harvard Law School International Human Rights Clinic (2016) reported that the current efforts

by the South African government to mitigate these legacies and associated impacts are inadequate and are failing to meet acceptable standards regarding human rights obligations. Although there is currently a renewed interest in the reclamation of the defunct gold tailings deposits, including those in the Davidsonville and Riverlea area (CRG, 2016), this could, in fact, aggravate the environmental impacts and seriously affect the community over the short (< 3 years) to medium (>3≤10 years) term if not treated with care. Pollution arising from defunct gold tailings deposits is of concern to many South African communities, especially in the Gauteng Province. Most of these defunct gold tailings deposits are not rehabilitated, have unstable slopes, and the presence of radioactive materials are among the primary concerns across South Africa (Bakatula and Tutu, 2016; Durand, 2012; Mphephu, 2003). Post-2001, many newspaper articles and documentaries have emerged in which society has associated their health problems with mining gold activities (Health-e, 2017; Venter, 2006; Kardas-Nelson, 2010). One example is Davidsonville, Roodepoort which has a defunct gold tailing dump that remains un-rehabilitated. There are houses built less than 50 m from the defunct tailings dump. Due to the pollution arising from this tailings dump, the community has associated their sicknesses to the tailings dump. This has caused conflicts between the community and government, resulting in a court case.

1.2. Problem statement

Gold mining generates significant quantities of tailings waste. These tailings can have a significant impact on the surrounding environment, with concomitant effects on local eco-systems, as well as human health and on quality of life. The latter is a particular concern in the Witwatersrand goldfields of South Africa, where communities are located in close proximity to gold mining operations and/or both current and defunct tailings dumps. The complex relationships between mine waste, the environment, and community health are still not well understood, making it difficult to justify and motivate the implementation of meaningful interventions to mitigate risks associated with mine dumps. To date, little attempt appears to have been made to support community concerns and perceptions with factual evidence and information.

1.3. Aim and objectives of the research project

The aim and objectives of the research project are as follows:

1.3.1. Aim of this research project

The overarching aim of this research study is to develop a better understanding of the facts, perceptions, concerns, and expectations associated with Witwatersrand gold mine tailings storage facilities, and how these are related.

1.3.2. Research objectives

The aim of this study is fulfilled through three main objectives:

- (i) Review and critically assess the relevant literature pertaining to the environmental impacts and the social impacts (that is, livelihoods, quality of life and health of the society) of gold mining, processing and defunct gold tailings.
- (ii) Establish the community's, civil society organisations', and subject experts' perceptions, experiences, and expectations about the socio-environmental impacts caused by defunct gold tailings in Davidsonville.
- (iii) Analyse the extent to which current community concerns and expectations have been addressed or perceived to have been addressed by responsible parties (for example, gold mining companies and/or the government).

It is envisaged that the fulfilment of these objectives will ultimately serve to facilitate the development of sustainable solutions to the concerns and conflicts associated with defunct gold tailing deposits. This study forms part of a broader project sponsored by the Water Research Commission titled "Resource Efficient and Socially Responsible Approaches for the Integrated Management of Mine Wastes: Understanding the Opportunities, Enablers, Barriers and Risks" under the leadership of Associate Professor Jennifer Broadhurst.

1.4. Project Scope

A multi-method approach is adopted to achieve the above-mentioned objectives, with the scope of work for this study being conducted in two phases:

- **Phase 1 - Desktop study:** Involves a detailed review of published academic literature, company reports, newspaper articles, gold mining magazines, and specialist reports, with the intention of meeting the first objective of this study. Specific emphasis will be placed on Gauteng Province, particularly the Central Rand goldfields area of the Witwatersrand because the impacts are deemed significant in these areas and the area records the highest number of defunct tailings per square kilometre.
- **Phase 2 - Semi-structured interviews:** Involves semi-structured interviews with representatives from communities, civil society organisations, and independent experts, with a view to meeting the second and third objectives of the project. Here, the focus will be placed on defunct tailings in Davidsonville.

It should be noted that this study is only concerned with the impacts and effects arising from defunct gold tailings deposits. This indicates the potential long-term consequences associated with gold mining post-closure. The study did not interrogate perceptions of mining companies or government

representatives as it was considered beyond the scope of work. Also, the broader environmental and health impacts related to gold mining in general fall outside of the scope of the study and are therefore not included.

1.5. Dissertation structure

A schematic showing the structure of the dissertation is presented in Figure 1-2. The Introduction in Chapter 1 has provided a background of the study outlining the project aim, objectives and scope. Chapter 2 provides the desktop study with the relevant literature review which covers the extent of gold tailings storage facilities, potential environmental impacts, and socio-economic impacts including health impacts, consistent with the scope of work for Phase 1 of the study. The results of the semi-structured interviews with the relevant stakeholders and interpretation of the results are shown in Chapter 3. Lastly, the conclusion and recommendations for future work are presented in Chapter 4.

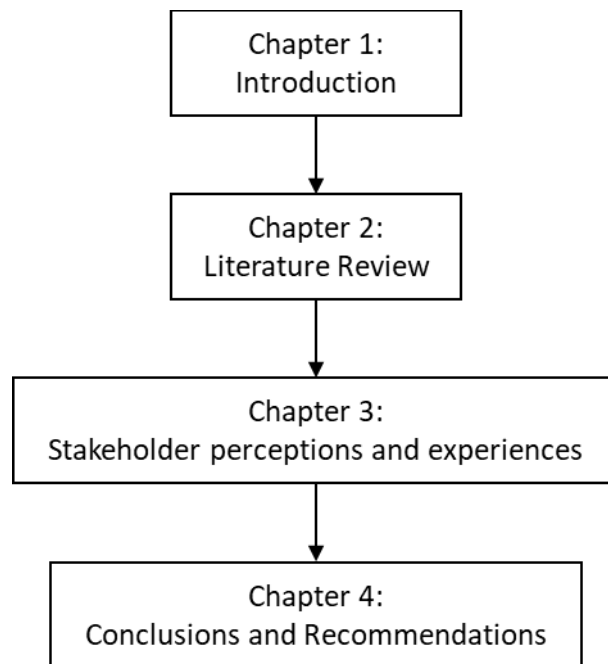


Figure 1- 2: Schematic representation of the dissertation showing the four main chapters.

CHAPTER 2

LITERATURE REVIEW

South Africa is a classic example of how gold mining can help build a world-class economy and, at the same time, have long-term environmental impacts. In terms of the latter, gold tailings deposits are of particular relevance as they are often associated with environmental degradation and affect the health and livelihoods of many communities who live in the vicinity of defunct gold tailings deposits. Consistent with the first objective of this study, this chapter reviews and analyses the current literature pertaining to gold tailings deposits with specific emphasis on (a) Generation, management, and properties of gold tailings dumps (section 2.1); (b) Environmental emissions and impacts (section 2.2); (c) Community health and quality of life (section 2.3); (d) South African case studies: Conflicts and incidents (section 2.4); (e) Interventions to mitigate environmental and social impacts (section 2.5) and; (f) Summary and synthesis. In order to ensure that there is sufficient coverage of literature, published academic articles, company reports, a legal framework from government gazettes, newspaper articles, and reported conflicts about defunct gold tailings deposits are reviewed.

2.1. Generation, management and properties of gold tailings dumps

2.1.1. Generation and management of gold tailings dumps

There are two principal activities of gold mining that produce waste, that is, (a) mine development and production (i.e. mining) which is the extraction of the gold ore from the mine either during developmental stages or routine production cycles, and, (b) mineral processing and beneficiation which is the extraction and refining of the desired product (Lottermoser, 2007). Mining is done using several methods and equipment which often involve blasting or fracturing of the ore using explosives or trenching using heavy machinery. Mined products (i.e. run-off-mine) are often transported to short- and medium-term storage facilities known as stockpiles. In the stockpiling area, preliminary ore sorting may be introduced to separate gold-bearing material from gangue material. This introduces a first phase of waste rock dump generation. From the stockpiles, gold-bearing material is transported to the mineral processing plant where it is subjected to a number of processes. The first stage of gold ore processing involves comminution which is a mechanical process (i.e. crushing and grinding) used to reduce the size of the ore. The second stage involves ore conditioning where hydrated lime (quick lime) is added to the thickened material with the aim of preparing the ore for further sorting and cyanide leaching. The thickened and conditioned material is either sent to a series

of leaching tanks, followed by activated carbon absorption (carbon-in-pulp, CIP), or carbon-in-leach (CIL) process. Gold loaded in carbon is sent for further processing through subjecting it to elution, electrowinning and refining processes. Pulp material from leaching is subjected to cyanide detoxification followed by pumping into a tailings storage facility (Figure 2-1).

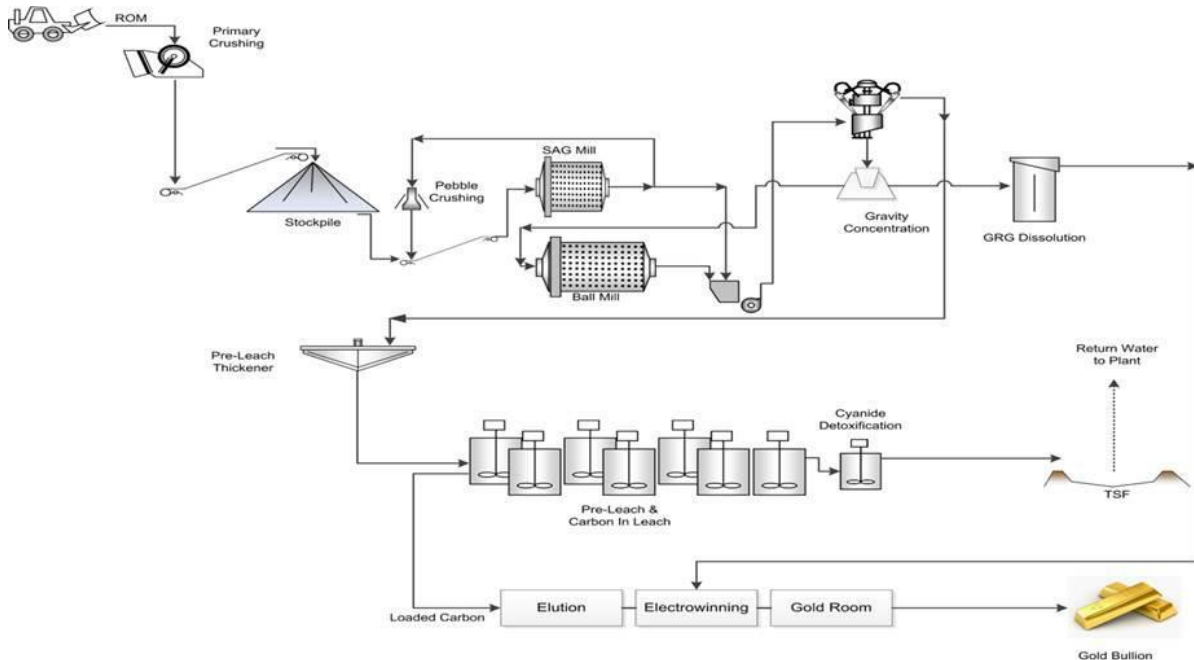


Figure 2- 1: A simplified gold ore processing and beneficiation flowsheet (Modified after Nwaila et al., 2019).

An average size operating Witwatersrand gold mine mills 34082.5 metric tonnes of gold ore with a density of 2.75 t/m³ and a belt grade of 5.2 g/t (Sibanye Stillwater, 2018). At a plant recovery factor of 97 % and elution efficiency modifying factor of 98 % to 99 %, the gold recovered amounts to 0.17 metric tonnes (Sibanye Stillwater, 2018). This implies that a total of 99.9 % (34082.3 metric tonnes) of the milled tonnes is deposited as waste. Therefore, for every 1 metric tonne of gold produced, a total of 199 624 metric tonnes of waste is produced. About 5 % of gold mining waste material is often utilized for backfilling purposes.

In most of the Witwatersrand goldfields, the majority of the tailings storage facilities are not properly rehabilitated, with some classified by the Department of Mineral Resources as ownerless. Several tailings storage facilities, such as those in the Central Rand goldfield (e.g., Princess Tailings), were created many decades ago and the owners are no longer known. Tailings storage facilities are possibly the most prominent structures built by man in the Witwatersrand goldfields (Vermeulen, 2001; DEA, 2018). Over the last few decades, the volume of tailings being generated has increased exponentially with the increase in the demand for minerals and metals, and the mining of many low-

grade ores (DEA, 2018). Gold grade of these tailings varies between 0.1 and 1.2 g/t, with an average of 0.35 g/t (Sibanye Stillwater, 2018). Historically, the impacts of tailings were not well understood, hence opportunities to mitigate their impacts were not realised. Advancement of processes and the need to clean the environment has led to tailings reclamation initiatives championed by companies such as DRD Gold, Central Rand Gold and Mintails Group (Ojelede et al., 2012). Some of these companies have succeeded in the reclamation initiatives and merged with primary gold producers such as the merger between Sibanye Stillwater Limited and DRD Gold. Other companies, such as Mintails Group, did not succeed due to increasing environmental rehabilitation costs, low investor confidence, and the cost of reclamation, and thus ended up being liquidated. Figure 2-2 shows the distribution of tailings deposits and their absolute distance (buffer zone) to residential areas.

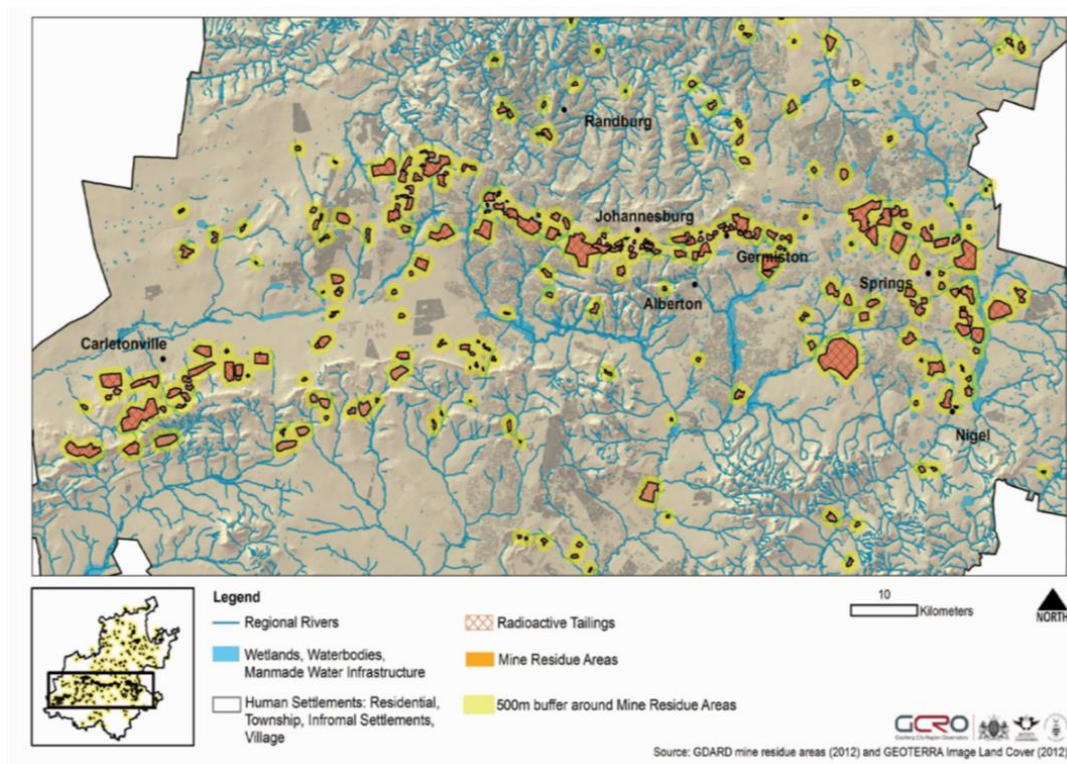


Figure 2- 2: Defunct radioactive gold tailings deposits and their proximity to watercourses and residential areas (After Bobbins, 2015).

In most of the defunct Witwatersrand TSFs, co-disposal of tailings with waste rock dumps was a common practice until the mid-1980s (Van Niekerk and Viljoen, 2005). At the time of deposition, one of the benefits of this type of method included minimisation of waste footprint, since only a few piles would be laid per mine site (Van Niekerk and Viljoen, 2005). In most parts of the dormant Witwatersrand gold mining, tailings were deposited without the consideration for the environment and constructed with poor design and lack of rehabilitation (Ngigi, 2009). Many of the defunct tailings were constructed in areas that were never planned for permanent human habitation, and legislation

was not very stringent. What is left in many parts of the country where mining ceased to operate, are large piles of unrehabilitated poorly designed TSFs. Some of the issues currently encountered in defunct tailings in various parts of the Witwatersrand goldfields is embankment foundation problems which involve the support of the embankment by natural soil. Much of geotechnical studies of TSFs in South Africa remains unpublished, except where noticeable failures have occurred (e.g. failure of a 31 m high northern wall of the number four tailings dam of the Harmony Gold mine on the night of 22 February 1994, Merriespruit, a suburb of Virginia in the Free State goldfield of South Africa; Van Niekerk and Viljoen, 2005).

2.1.2 Properties of gold tailings

Vermeulen and Rust (2002) reported that the chemical composition of the Witwatersrand gold tailings dumps varies significantly on the impoundment both with width and spatially. Their study also proved that the composition of the tailings is directly dependent on the mineralogical and chemical composition of the ore and the process of mineral extraction. In order to understand the composition of the tailings' deposits, the mineralogical and chemical composition of the auriferous and uraniferous quartz-pebble conglomerates ("reefs") is essential.

The Witwatersrand auriferous and uraniferous rocks (reefs) occur as either conglomerates or kerogen seams (Robb and Meyer, 1995; Frimmel and Nwaila, 2019). In the conglomerates, the rock pebbles are cemented in the silicate matrix. The pebbles are commonly derived from vein quartz and may also comprise quartzite, chert jasper, and quartz porphyry, and vary in composition, size and colour. The matrix consists of pure silica, but also contains tiny flakes of muscovite and pyrophyllite, as well as visible pyrite and other sulphides such as pyrite (FeS_2), Pyrrhotite (Fe_{1-x}S), arsenopyrite (FeAsS), chalcocopyrite (CuFeS_2) and galena (PbS). Table 2-1 shows averaged mineralogical composition results of a typical Witwatersrand gold ore.

Table 2 - 1: Typical mineral composition of the Witwatersrand gold ores (Nwaila et al., 2019)

Mineral	Abundance
Quartz	70 – 90 %
Mica and chlorite	10 – 30 %
Pyrite	2 – 4 %
Other sulphides	1 – 2 %
Carbonates and oxides	1 – 2 %
Gold	~0.1-50 g/t

Consistent with the composition of the typical Witwatersrand gold ore (Table 2-1), a study by Nengovhela et al. (2006) found that the mineralogical composition of the Witwatersrand gold tailings located in Brakpan, Knights, Edenvale, Roodepoort, Klerksdorp, and Carletonville in addition to quartz (69-90 %) include pyrophyllite (3 to 22 %), chloritoid (2 to 20 %), mica (3 to 11 %), chlorite (3-10 %), jarosite (1 to 2 %), pyrite (1 to 2 %), gypsum (~1 %), and clay minerals (~1 %) coinciding with the ore properties. The surface (top) these dumps is oxidised due to exposure to air and water, and the oxidation has resulted in the formation of acid in the pore water (Vermeulen and Rust, 2002).

Comparisons between older tailings and modern tailings show that the older tailings dumps generally contained far coarser “sands” (>90 μm) due to the older technologies used to process gold ores, while younger tailings dumps are relatively fine (average of ~75 μm) (Vermeulen and Rust, 2002). Figure 2-3 shows particle size distribution of the older Witwatersrand gold tailings dumps.

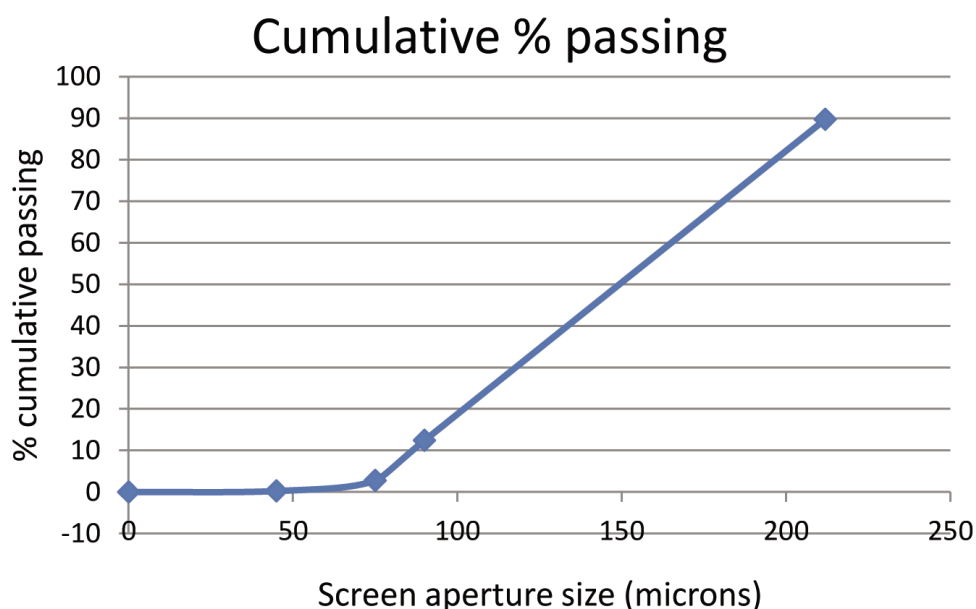


Figure 2- 3: Particle size distribution of the Witwatersrand gold mine tailings (Malatse and Ndlovu 2015)

The elemental composition of the Witwatersrand tailings varies significantly in terms of their chemical composition. Malatse and Ndlovu (2015) calculated an average composition of Witwatersrand defunct tailings (Table 2). The averaged composition is in agreement with the mineralogical composition and their proportions presented in Table 1-1. The sulphur content provides an indicative sulphide mineral composition (e.g., pyrite composition).

Table 2 - 2: Major constituents of the gold mine tailings (Malatse and Ndlovu 2015)

Component	Composition (wt %)
<i>Major element</i>	
SiO ₂	77.7
TiO ₂	0.469
Al ₂ O ₃	10.2
Fe ₂ O ₃	4.51
MgO	1.79
<i>Minor element</i>	
MnO	0.0549
CaO	1.93
Na ₂ O	0.613
K ₂ O	1.19
P ₂ O ₃	0.085
SO ₃	0.905
<i>Trace element</i>	
Cr ₂ O ₃	0.45
NiO	0.0177
Co ₂ O ₃	0.0063
CuO	0.007
ZnO	0.008
As ₂ O ₃	0.01
Pb ₂ O	0.0041
SrO	0.0151
ZrO ₂	0.0312
U ₃ O ₈	0.0064
Total	100

Relative to crustal averages or uncontaminated environments, the mean concentrations of As, Au and U in four major tailings of the Witwatersrand (that is, Central Witwatersrand (CWJH), Central Witwatersrand Roodepoort (CWRD), Eastern Witwatersrand Springs (ERSP), and Eastern Witwatersrand Boksburg (ERBK)) were found to be highly enriched (Maseki, 2013). Notable are enrichment in Pb concentration which is higher at CWRD, CWJB and ERSP (Table 2-3). At CWJB, ERBK, and ERSP the Cr and Ni concentrations are above the crustal average. Across all the four TSF complexes that were studied, the mean concentrations showed that As, Au, U, Pb, Cd, Cr, and Ni are all above the crustal averages.

Table 2 - 3: Measured mean concentration of metals in the gold mine tailings storage facilities (TSFs) compared to Earth crustal averages (bold indicates above crustal average) (ppm) (After Maseki, 2013)

Element	Mean concentrations in each TSF				Mean concentrations across the four TSFs	Concentration in the continental crust #
	ERSP	ERBK	CWJB	CWRD		
Fe	40500	42200	44800	21300	37100	43200
K	19700	21000	10670	2200	11700	21400
Mn	205	220	325	160	240	716
Cr	410	550	230	120	290	126
Zn	40	30	70	30	46	65
Ni	106	60	76	16	60	56
As	150	140	90	110	116	1.7
U	8	7	16	16	13	1.7
Pb	16	11	27	24	21	14.8
Cd	0.10	0.08	1.52	5.67	2.42	0.10
Au	0.52	0.72	3.91	1.30	2.09	0.0025

2.2. Environmental emissions and impacts

The gold mining legacy of South Africa did not only bring benefits, but it has also left over 215 un-rehabilitated tailings storage facilities where very little was done in the past to preserve the environment, and no legislation was enacted, the result of which is showing now through socio-economic and environmental impacts (Rösner, 1999). Environmental degradation from gold TSF spreads far beyond the TSF sites in the form of air pollution (Mizelle et al., 1995), soil pollution (Rösner and van Schalkwyk, 2000; Rösner et al., 2001) and water pollution (Naiker et al., 2003; Tutu et al., 2008). As a result of environmental degradation, metals and metalloids from the tailings storage facilities are transported in various pathways and result in several environmental and health impacts (Figure 2-4). Environmental impacts include atmospheric, lithospheric, soil and water pollution. According to Durand, 2012, pollution by the Witwatersrand and Far West Rand gold TSFs will continue for as long as they take to erode away. Worsening pollution is that many of these TSFs were built on the continental divide and on top of a very large karst aquifer (that extends from the North West Province, to Gauteng, into Mpumalanga and Limpopo Province), thus polluting two

separate river systems and the groundwater that several towns, rural communities, and farms that are located on the karst system depend on (Durand, 2012).

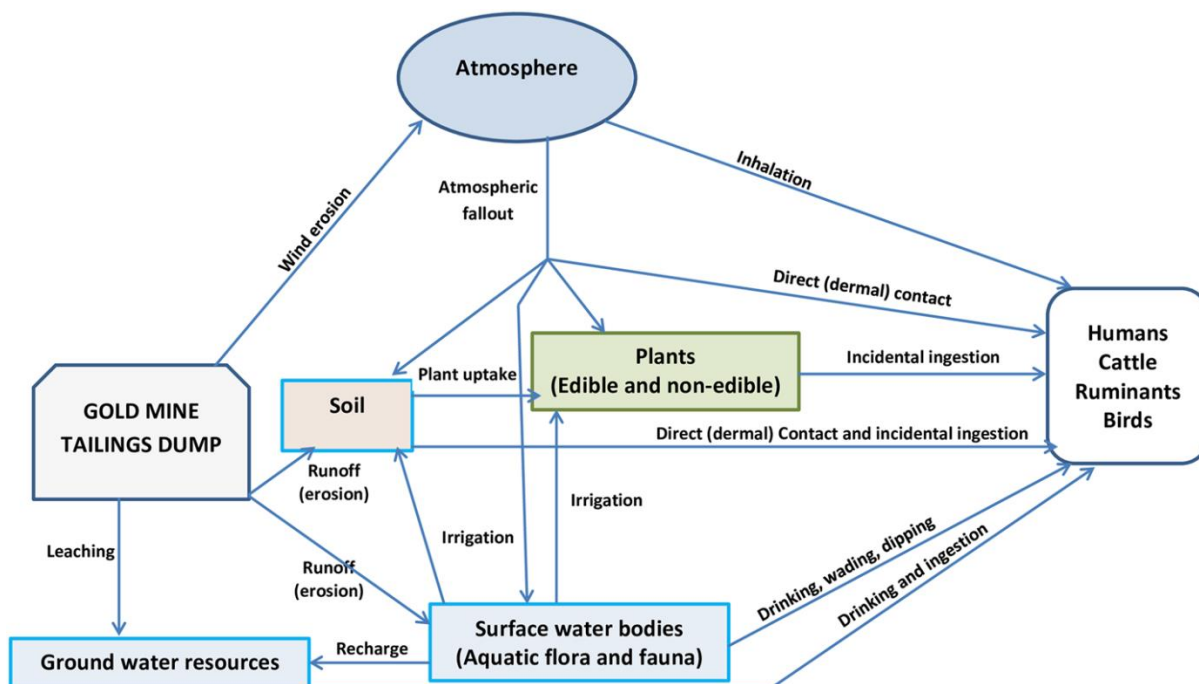


Figure 2- 4: Conceptual illustration of pathways of metals and metalloids from the tailings storage facilities in the environment potentially leading to exposures for ecological receptors and humans (After, Ngole-Jeme and Fantke, 2017).

2.2.1. Air pollution

The gold TSFs in the Witwatersrand goldfields are either being reclaimed for their residual gold, or they remain dormant with little or no vegetation cover, or have other rehabilitation measures (Kneen et al., 2015; Andraos et al., 2019). Therefore, dust emissions from both reclaimed and dormant TSFs are a reality. Unrehabilitated TSFs are susceptible to physical erosion as they have steep slope angles and are elevated above natural ground contours. Defunct gold tailings generate excessive dust (Figure 2-5) during windy-seasons and are one of the main sources of air pollution (Getaneh and Alemayehu, 2006). In a study conducted by Wright et al. (2014), about 55.6 % of the focus group identified the TSFs as the biggest source of dust, followed by sandblasting at 22.2 %, coal yards at 11.1 %, and dry season at 11.1 %. As it has been shown in Section 2.1, the gold tailings material behaves like soil containing silt to sand sized grains. During windy dry seasons these fine dust particles from the tailings and rock dumps are released into the immediate atmosphere, contributing to the localised load of potentially toxic particulate matter (PM) which is an airborne mixture of suspended microscopic solid particles and liquid droplets.



Figure 2- 5: Dust visible from the gold TSFs (Photographer: Nwaila, PC).

In the Witwatersrand, it is a common phenomenon to have severe episodes of windblown dust from the TSFs, particularly in the spring windy season (Maseki, 2013). Closer to the TSF (<500 m distance from the TSF), the ambient particulate matter 10 (PM_{10}), which is thoracic coarse particles or coarse-fraction particles; generally including particles with a nominal mean aerodynamic diameter greater than $2.5\ \mu\text{m}$ and less than or equal to $10\ \mu\text{m}$, aerosol concentrations can go up to $2\ 000\ \mu\text{g.m}^3$ (24-hour average), especially during the spring season (Maseki, 2013). Recent studies indicate that sporadic dust events produce particulate matter (PM_{10}) and, specifically, crystalline silica dust concentrations that are unhealthy at distances of up to 2 km downwind from the TSFs (Kneen et al., 2015). Fine dust from tailings and rock dumps have a negative effect on visibility when it forms dust clouds, while deposition of dust on fabrics, buildings, skin, eyes, and water tanks constitute a nuisance and other health issues (Nkosi, 2016).

2.2.2. Water pollution

Emissions from mining waste deposits to the environment cause great and generally irreversible damage to the ecosystems (Oelofse, 2008). A global census revealed that, by 1989, approximately 19 300 km of streams and rivers globally were estimated to have been seriously affected by mine waste deposits, as were approximately $720\ \text{km}^2$ of lakes and reservoirs, though the true scale of the environmental pollution caused is hard to evaluate and measure accurately (Johnson and Hallberg, 2005; Oelofse, 2008). In South Africa, a surface and ground water impact study by Oelofse et al. (2010) showed that gold mining and tailings storage facilities have contaminated both surface and ground water. There are four main types of mining waste impacts on water quality, namely (a) acid

mine drainage, (b) metal and metalloids contamination and leaching, (c) processing chemicals solution, and (d) erosion and sedimentation (Dold and Fontbote, 2002; Weber et al., 2004).

Acid mine drainage (AMD) is a natural process whereby sulphuric acid is produced when sulphides in rocks are exposed to air and water. However, the interactions between rainwater, surface streams, and tailings can lead to contamination of surface and ground water, and the production of AMD (Scott, 1995; Rösner et al., 2001). Acid mine drainage severely degrades water quality, and can kill aquatic life and make water virtually unusable (Humphries et al., 2016). Metals and metalloids pollution (e.g., arsenic, cobalt, copper, cadmium, lead, silver, and zinc) occur when surface excavated rocks or underground blasted rocks come in contact with water. Metals are leached out and carried downstream as water washes over the rock and land surface. In AMD affected areas, metals become highly mobile, thus enhancing pollution (Tutu et al., 2009). As indicated in section 2.1.2 the major minerals in the tailings materials are quartz, mica, chlorite/chloritoids, and pyrite. A study by Yibas et al. (2010) found that some of the Witwatersrand tailings dams contain pyrophyllite and traces of K-feldspar. The Witwatersrand tailings dams that they studied showed oxidation of pyrite. A study by Naicker et al. (2003) found that the groundwater within the East Rand goldfields is heavily contaminated and acidified due to oxidation of pyrite (FeS_2) from mine tailings dumps material and has elevated metal concentrations. Furthermore, the upper 20 cm of soil profiles are severely contaminated by metals because of the evaporation of groundwater and capillary rise where the water table is close to surface. Contributing 20 % of the stream discharge, this polluted groundwater is discharging into the surface water streams, resulting in the pH of these streams lowering. As a result of oxidation, Fe and Mn precipitate in the stream while other metals are being removed by co-precipitation. The toxic effect of the addition of contaminated water persists for more than 10 km beyond the source of pollution (Naicker et al., 2003).

Processing chemicals pollution occurs when chemical agents such as cyanide or sulphuric acid, used by mining companies to separate the desired mineral from the gangue spill, leak or leach from the mine site into nearby water bodies (Wittmann and Förstner, 2000). These chemicals can be highly toxic to humans and wildlife. Lastly, erosion and sedimentation pollution occur when there is inadequate prevention and control strategies around tailings storage facilities (Getaneh and Alemayehu, 2006; Abdul-Wahab and Marikar, 2012). Erosion of the exposed gold tailings may carry substantial amounts of sediment into streams, rivers, and lakes. Higher sediment load can clog riverbeds and smother watershed vegetation, wildlife habitat, and aquatic organisms (Ntsume and McCarthy, 2005; Humphries et al., 2016). In South Africa, areas that are known to be mining districts, such as Klerksdorp, Orkney, Stilfontein, Hartebeespoort, and Evander, have all been identified as

probable affected areas by AMD (DWA, 2010; Bobbins, 2015). Figure 2-6 shows AMD from a stream between Central Rand and West Rand tailings storage facilities.



Figure 2- 6: Acid mine drainage from a stream between Central Rand and West Rand tailings storage facility (www.mining.com).

2.2.3. Soil pollution

Physical erosion, wind erosion and AMD emissions can all result in soil contamination. For example, the water from AMD results in the acidification of the soil, thus increasing the exchange between hydrogen ion and nutrient cations such as potassium (K), magnesium (Mg), and calcium (Ca) in the soil (Sigh and Agrawal, 2006). As a result, these cations are released into the soil and can be rapidly leached out in soil solution along with sulphate from the acid input. The acid-induced leaching results in nutrient deficiency for the affected soils. As a result, loss of soil fertility results in the decrease of plant growth, including trees on acidified soil (Sigh and Agrawal, 2006). The acidification of soil also affects nutrient cycling and decomposition rate in the soil negatively.

A study by Taylor et al. (2005) noted that AMD contaminated soils are a major limitation on vegetation types that can be utilised for rehabilitation and, at worst, are responsible for a failed rehabilitation plan. Another study by Rösner and van Schalkwyk (2000) reported that the topsoil (that is, layer of soil below the tailings dump material) of the exposed reclaimed tailings dumps to the east of Johannesburg is highly acidified (with a pH between 5 and 7) and contaminated with metals,

particularly Co, Ni, and Zn. Calcium concentrations were also found to be relatively high. Most of these metals were seemingly not readily absorbed by the soil, but due to acidic conditions of the soil, these metals become mobile, easily soluble, and are in an exchangeable form. They, thus, have the potential to be leached into the groundwater in the longer term, resulting in sustained pollution (Rösner and van Schalkwyk, 2000). Metal contamination seems to increase towards the surface, which can be attributed to downward migration of metals (Naicker et al., 2003; Rösner and van Schalkwyk, 2000).

(i) Effects on ecosystems

The irreversible nature of metal and metalloids contamination results in an accumulation of metals in sediments, soils, and the environment at large. It is toxic to plants, having the capacity to bio-accumulate, thus posing a health risk to humans and animals (Bobbins, 2015). Chubuike and Obiora (2014) identified that the negative impacts of metals in plants included oxidative stress, effects on fluorescence, stomatal resistance, chlorophyll and photosynthesis, reproductive processes, seed germination, seed morphology, and seed physiology. High concentrations of metals also affect soil microbial activities negatively, causing reduction in soil microbial population and distribution, and low microbial enzymatic activities (Sobolev and Begonia. 2008; Ngole-Jeme and Fantke, 2017). Studies conducted by Eisler (2004) have shown that arsenic (As) doses of 17 mg/kg to 48 mg/kg body weight were terminal to birds, while some mammals were adversely affected by As doses of 2.5 mg/kg BW after oral exposure (Ngole-Jeme and Fantke, 2017).

In the study by Kootbodien et al. (2012) that investigated the potential metalloids contamination in a school vegetable garden that is situated near a mine tailings dump, the school soil was found to have high levels of arsenic (30.5 ppm) as well as elevated concentrations of lead and mercury in the school vegetables. Naicker et al. (2003) study found out that the surface soil layer along the bank of the Nelspruit stream, which is situated in close proximity to gold TSFs and is highly enriched with metalloids, has been created as a result of evaporation of groundwater of the capillary zone above the water table. In dry winter months, a gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) crust that is rich in metalloids also develops on this surface. As a result, vegetation is no longer supported, due to the contaminated surface soil together with the increased metalloids loads in the streams..

2.3. Community health and quality of life

Health and quality of life for communities located within close proximity to tailings dumps are most likely to be adversely affected. Various forms of pollution such as air, water, and soil pollution arising from the dumps have a direct impact on the community quality of life. Generally, and as shown in

section 2.1 and 2.2, mine waste and tailings produce large concentrations of effluents which contain high levels of potentially harmful elements. These elements tend to migrate into various compartments of the ecosystem, resulting in undesirable health consequences affecting the quality of life (Ngure et al., 2014). Moreover, many government reconstruction development project houses (referred to as RDP houses) built for low-income earners appear to have been allocated to land close to TSFs and landfill sites of active or derelict mines (Manungufala et al., 2005). Thus, still located in close proximity to TSFs are many older and poorer townships, informal settlements, and government-provided low-income housing estates (Bobbins, 2015).

2.3.1. Health

Dust fallout, especially particulate matter, is one of the major contributors to health impacts. Studies that focus on the effects of particulate matter have shown that particulate matter that is $<2.5\ \mu\text{m}$ in size ($\text{PM}_{2.5}$) is able to settle in the respiratory system (Wichers et al., 2011). In some instances, particulate matter carries potential toxic metals and metalloids (Maseki, 2013). The Department of Environment, Fisheries and Forestry (DEFF) in South Africa has set permissible particulate matter emissions of $75\ \mu\text{g.m}^3$ for PM_{10} for 24 hours averaging time and concentrations of $40\ \mu\text{g.m}^3$ for 1-year averaging time (DEFF, 2020). The permissible particulate matter emissions for $\text{PM}_{2.5}$ is $65\ \mu\text{g.m}^3$ for 24 hours averaging time and concentrations of $25\ \mu\text{g.m}^3$ for 1-year averaging time (DEFF, 2020). However, the World Health Organisation (2006) noted that there is 'no safe threshold' level of particulate matter exposure for human health. Few studies have focused on the direct impacts of tailings dust fallout. Kneen et al, (2015) focused on particulate matter exposure levels within residential areas such those of Davidsonville residents, and found that there is higher exposure to residents who live in areas near tailings. Nkosi et al (2015) focused on the nature and composition of the dust fallout. Their study showed that air around residential areas that are located near tailings storage facilities contains crystalline silica and radionuclides. They concluded by stating that long exposure to toxic dust could lead to skin irritation, wheezing and asthma (Nkosi, 2016).

A recent study by Andraos et al. (2019) demonstrated that all population groups are susceptible to dust-related diseases; however, children are at a higher risk. According to Andraos et al. (2019) this is because children (a) spend more time outdoors; (b) compared to adults, have higher breathing rates relative to body weight; (c) have a higher oxygen demand, which results in higher particle deposition; (d) consume more, possibly contaminated, water and food per unit body weight; (e) have immature lungs and immune systems and; (f) due to early exposure, have more time to develop chronic diseases. Schools that are located in the vicinity of mine dumps are at risk of air pollution, such as PM_{10} and silica (Nkosi et al., 2015). Children from such schools and communities located in

the vicinity of TSFs are vulnerable to respiratory disease, and cases of asthma have been reported in certain areas (Nkosi et al., 2015).

Studies that focused on metals and metalloids contamination recorded potential hazards to human health since most metals and metalloids are not easily biodegradable and, subsequently, can accumulate in human vital organs, causing varying degrees of ailments based on acute and chronic exposures. The ailments vary from neurotoxic to carcinogenic actions (ATSDR, 2008; Morais et al., 2012). The most widely released metals in Witwatersrand tailings are Pb, Cd, Hg, and As. These metals and metalloids have an adverse health impact on humans (Table 2-4) upon exposure, even at low concentrations. A study by Maseki et al., (2017) that analysed 30 metals from the central and east Witwatersrand TSFs surface material showed that As, Cd, Cr, Pb, and U were enriched by a factor of two or more above the average crustal composition, and at concentrations that could be of possible health concern.

Table 2 - 4: The effects of metals on human health (Fashola et al., 2016)

Metals	Effects
As	Peripheral vascular disease, lung, skin, kidney and bladder cancer, severe to disturbances of the cardiovascular and central nervous systems which may lead to death, bone marrow depression, haemolysis, hepatomegaly, melanosis, polyneuropathy, and encephalopathy may also be observed.
Cd	Bronchial and pulmonary irritation, kidney stone, liver damage, various system disorders such as nervous and immune system, blood, bone and Itai Itai disease.
Cr	Skin rashes, stomach and ulcers upset respiratory problems, weakened immune systems, kidney and liver damage, alteration of genetic material, lung cancer and death. Chromium hinders enzyme activity, DNA damage, altered gene expression and causes mutations.
Cu	Accumulation in liver, kidney, brain, and cornea leading to cellular damage and Wilson's disease, upper respiratory tract and nasal mucous membrane irritation, haemolytic anaemia, epigastric pain, nausea, dizziness, headache, and death may occur.
Pb	Blood-related disorders such as colic, constipation and anaemia, high blood pressure, decrease of haemoglobin production, kidney, joints, reproductive and cardiovascular systems disorder, long-lasting injury to the central and peripheral nervous systems, loss of IQ, low sperm count, loss of hearing.

Hg	Affect gene expression, kidney damage, tremor, restlessness, anxiety, and depression and sleep disturbance, paraesthesia and numbness in the hands and feet while high doses may lead to death. Total brain damage can occur in early exposure while late exposure results in localised damage to the cerebellum, motor cortex, and the visual cortex.
Ni	Hypoglycaemia, asthma, nausea, headache, cancer of nasal cavity and lungs.
Zn	Tachycardia, vascular shock, dyspeptic nausea, headache, cancer of nasal cavity and lungs, asthma, vomiting, diarrhoea, hypoglycaemia, pancreatitis and damage of hepatic parenchyma, impairment of growth and reproduction.
U	Kidney damage and damage to the respiratory tract.

2.3.2. Quality of life and livelihoods

The impacts of gold TSFs extend beyond environmental impacts and affect the overall quality of life and livelihood of human beings living in their vicinity. For example, it has been presented in section 2.3.1 how the environmental impacts have an effect on the health of communities residing in the vicinity of gold TSFs. Not only do TSFs occupy land that can be used for other land uses that are meaningful to the communities, but also results in the decline of agricultural lands, wetlands, wildland and forests.

2.3.2.1. Dust nuisance

As presented in section 2.2.1., the gold tailings dumps produce dust emissions. Apart from the health effects resulting from dust generated by gold tailings dumps (section 2.3.1.), it also impacts on the quality of life of communities as it is a nuisance. The fine materials of the gold tailings dumps are easily blown by the wind, which results in the surrounding communities being blanketed with clouds of dust. According to the IHRC (2016) respondents residing in the West Rand and Central Rand next to the gold tailings dumps, when it is windy, the area that they reside in gets white with dust. Furthermore, the respondents stated that the dust gets worse such that they cannot see where they are going. August and September are windy seasons, which results in acute dust problems, although the inhalation of dust is not limited to this windy season (IHRC, 2016). Respondents were reported stating that they could not escape the dust and that the dust is everywhere, including their homes, lungs and food. They are unable to get rid of the dust. Oguntoke and Annegarn (2014) state that there have been public complaints about dust from the TSFs, with weather aggravating the frequency and intensity of the dust emissions. According to this study, records of complaints from 1995 to 2010 were collected through the Crown Mines Dust Monitoring forum in Johannesburg and analysed

(Oguntoke and Annegarn 2014). The findings were that the frequency of complaints is more during the dry months between August and October.

In a study that was conducted by Wright et al., (2014) in Krugersdorp, all focus groups they interviewed agreed that dust is a nuisance to them as it causes health problems, damages their furniture and electrical appliances, and it contaminates the water. Furthermore, dust was identified as affecting animal life, soil, the environment in general, and food (Wright, et al., 2014). Communities residing near TSFs cannot avoid physical exposure to the TSFs. This is due to their homes being in close proximity to the TSFs. According to Wright et al., (2014), all of the focus groups they had interviewed agreed that they go near TSFs while children use the TSFs as playgrounds.

2.3.2.2. Effect on agricultural land and livestock

Once occupied by a farming community, within a few years the Witwatersrand was transformed into the densest populated area region in Southern Africa after the discovery of gold. With the TSFs being in such close proximity to communities, emissions as described in the previous section can affect quality of life and even the livelihoods. Pollution associated with acid mine drainage poses a nuisance and affects irrigation water, while windblown dust affects crop productivity (IHRC, 2016). The vegetable gardens serve as an important source of food and, to an extent, a source of income. Therefore, the difficulties with growing crops have had a noteworthy impact on residents, particularly those without jobs. As mentioned in section 2.2, metals are present in the Witwatersrand gold TSFs. According to Abdul-Wahab and Marikar (2012), metals are a cause of oxidative stress to plants, thus affecting photosynthesis, chlorophyll, fluorescence, and stomatal resistance. For example, copper hinders photosynthesis and reproductive processes, lead decreases chlorophyll production, while arsenic interferes with metabolic processes. Thus, plant growth is reduced or made impossible (Abdul-Wahab and Marikar, 2012). The IHRC (2016) indicated that when the plants survive, they might not be healthy for consumption, due to their toxicity and radioactivity of the soil (IHRC, 2016). It should be noted that there is a lack of detailed studies or documented evidence that link environmental pollution by gold TSFs to the community's livelihood in the Witwatersrand goldfields.

2.4. South African case studies: conflicts and incidents

This, coupled with the exclusion of community members in decision-making, has resulted in significant tensions between the government and communities, and increased the distrust for mining companies. While a number of communities have suffered the adverse impacts of gold mining in the West and Central Rand (see Figure 2-7), three of the most prominent cases include Davidsonville, Riverlea, and Tudor Shaft.

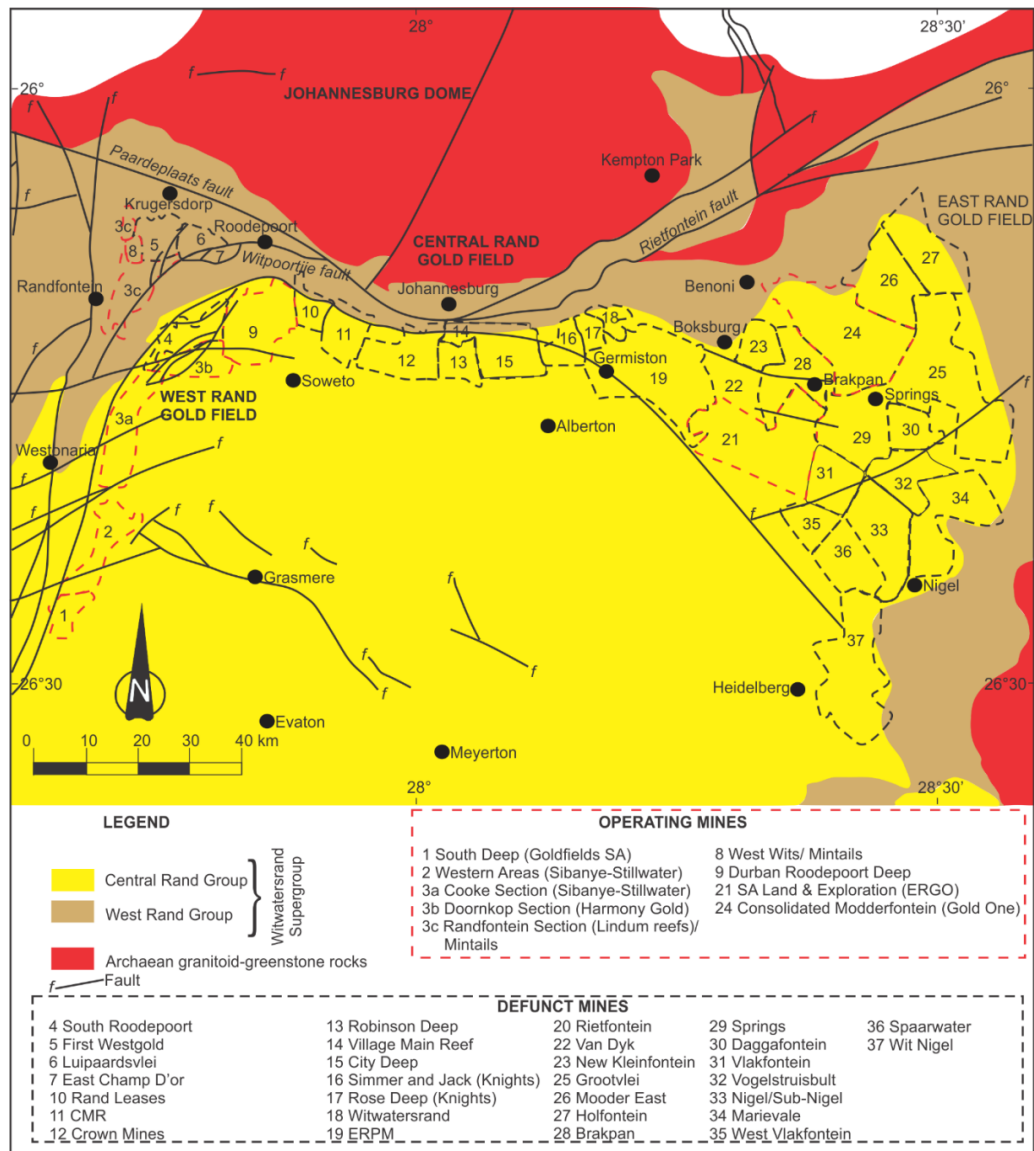


Figure 2- 7: Map showing the Central Rand goldfields and operating mines (Frimmel and Nwaila, 2019).

In spite of the many regions in South Africa that have been affected by gold mining waste, the selected residential area in this current study is part of a cluster of neighbourhoods that not only represent the early stages of mining in South Africa, but serve as an example that displays remnants of severe environmental impacts. In this regard the following places which fall within the City of Johannesburg, in the Central Rand goldfields of the Witwatersrand Basin, serve as South African case studies.

2.4.1. Case study 1: Riverlea

The suburb of Riverlea gives a good example to how gold mine TSFs have impacted the community residing in their vicinity. The suburb of Riverlea was established in 1963 to accommodate coloured

households. It is situated south-west of Johannesburg, Gauteng Province. The area is about 3.40 km² with a population of about 16226 people and 4208 households. It is a predominantly coloured community (coloured make up about 67 % of the total population). Riverlea is surrounded by both dormant and active tailings. Riverlea is located in the Central Rand district and situated in the centre downwind of gold TSFs (Figure 2-8). Despite the fact that mining had ceased for decades in this area, the last 7 years has seen small scale operations by companies such as Central Rand Gold and DRDGold.



Figure 2- 8: The suburb of Riverlea (After Google Earth, 2006).

A newspaper article by Kings (2013) titled 'Gold dust cripples Riverlea' highlights the conflicts that are associated with the gold mine TSFs. The community has been standing up for their rights as it has been affected by the dust from the DRDGold mine reclamation project that is reprocessing the TSFs. Since the beginning of this project in 2010, the residents of Riverlea have been complaining about health issues such as breathing, chest pains, and coughing that are related to the increased dust fallout. DRD Gold has been confronted by the community regarding increased dust levels and the health issues that they are experiencing. In their defence DRD Gold had acknowledged that the reclamation of the mine dump attracts dust and noise and that they were monitoring the dust levels and are working closely with the community (Kings, 2013a). As a further step to prove that the dust

is the cause of the health issues, Earthlife Africa was approached by the community of Riverlea on the 28 February 2014 to gain information about mining impacts on the community. However, Earthlife Africa was unable to access information such as the status of the mine and water use licences from the government, due to the Promotion of Access to Information Act (PAIA) (Bobbins, 2015). They were, however, able to obtain half of the requested information from Department of Water Affairs (DWA), which indicated probable environmental impacts such as metals and metalloids contamination. It has been noted that it is not easy to do epidemiological studies to state, exactly, the impact of a toxic substance that can drift on the dust. The residents had planned to take the legal route in order for them to attain the required information for them to prove that their health issues are caused by DRD Gold mining activities (Kings, 2013a; Kings, 2013b; Bobbins, 2015). However, funding limitations prevented residents from continuing with their plans.

Despite the fact that there are no epidemiological studies¹ conducted, the community members believe that their health problems are related to the gold mine tailings that they reside on top of (Bench Marks Foundation, 2017). Note that this is the community's perspective since there has been no scientific epidemiological studies to support this. In a study conducted by Bench Marks Foundation (2017) residents state that they have been residing in the area for up to 10 years and their children are sick from respiratory tract infections and chest pains since birth.

2.4.2. Case study 2: Davidsonville

The suburb of Davidsonville (26.1550° S, 27.8517° E) is located in Roodepoort town in the City of Johannesburg Local Municipality, Gauteng Province, (Figure 2-9). The area is about 1.62 km² with a population of about 5343 people and 1353 households. It is a predominantly coloured community area (75.01 % of the population). The study area is located at a relatively high altitude, reaching 1758 m above mean sea level. Prevailing wind direction is north-westerly with an average speed of about 4 m/s. Winds in the region are light, except for short periods, particularly in the spring months of September and October just before the rains, when strong winds are experienced.

Note 1: The study and analysis of the causes, patterns and effects of health and disease conditions.



Figure 2- 9: Davidsonville, Roodepoort (After Google Earth, 2006)

Davidsonville is situated near the historic “L” shaped Princess tailings dump and has been severely impacted and contaminated by it. Davidsonville is approximately 3 km north-west of Durban Roodepoort Deep Gold Mines. The exact date of deposition of the tailings is unknown, but records indicate that the Princess tailings dump predates 1933 (SRK, 2006). Some houses have been built on the edge of the Princess tailings dump, ignoring the 500 m buffer zone for houses and tailings dumps (Figure 2-10). This tailings dump consists of three dominant mineral groups, namely sulphides, oxides, and a variety of silicates (Dlamini, 2014). The Princess gold tailing dump was created by various gold mining companies which have since ceased to exist. Until the first phase rehabilitation in 2010, the Princess tailings dump was never adequately rehabilitated. The tailings dump is characterised by the unprotected slopes, which are susceptible to wind and water erosion, and the uncontrolled surface drainage which is continuously eroding the tailings into a nearby waterway and wetland. Disturbances are occurring on the site because of various activities such as driving over the tailings dump and the small industries (such as the brick making industry) located on site (SRK, 2006). Therefore, there is increased erosion of tailings which are suffocating the water system in the vicinity. Access to the site from existing road is smooth. Although there is fencing, no other signs are indicating that community members may not enter the tailings dump (Ngigi, 2009).

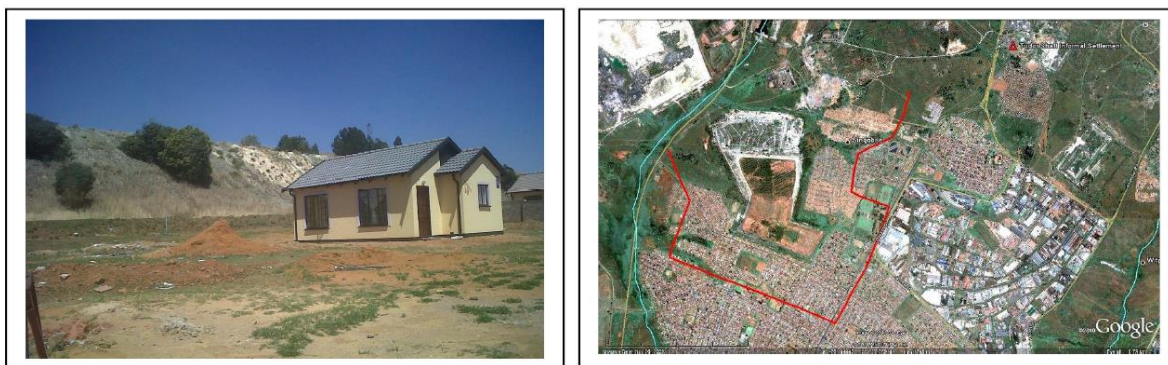


Figure 2- 10: Houses at the edge of the gold tailings dump (Turton, 2015)

A study conducted by Dlamini et al. (2016) found that pollution resulting from the Princess dump is severely impacting the water quality and the environment around the site. A high concentration of pollutants was observed, which are above the (Target Water Quality Range) TWQR as stipulated by DWAF (2001). It was also noted that AMD was active in the area, with the surface water showing AMD characteristics such as low pH, high concentrations of dissolved metals, and high levels of SO_4^{2-} ions. This can be ascribed to the existence of the TSF as well as the erosion of tailings material (Dlamini et al., 2016)

The study by Taylor and Maphorogo (2015) reported that the soil and water in Davidsonville is contaminated with metals, with the soil pH reaching 3.04, the water's pH of 3.24, and a contamination electrical-conductivity of 473 mS/m. Moreover, Davidsonville has also gained media attention following natural erosion and mine water runoff that continuously floods the Davidsonville community settlement area, making it muddy and unpleasant (Kardas-Nelson, 2010). The seepage of acidic waters from the dump floods residents' yards and leaves stagnant pools during the wet season. The Princess tailings dump is also situated across the road from a local public school, a man-made wetland called Davidsonville Dam, and Manuel Street Park, which further places strain to human health. Community members are associating their health problems with the tailing dump that is neighbouring their homes and is a nuisance during windy days. Therefore, there is a need for remediation and rehabilitation plans in order to improve the public open space of the people of Davidsonville and places of similar nature.

Due to a near century-long history of contaminated run-off, slime spillage, and dust emanating from Princess dump affecting the community, residents filed an application to the High Court of South Africa for a court order against the City of Johannesburg, Department of Mineral and Energy Affairs and DRDGold and its directors (Green Bond Investor Report, 2015; DRDGold, 2008). This court order was requesting urgent remedial action to be taken in order to address the environmental pollution

related to the Princess tailings Dump particularly (a) the toe seepage or shallow sub-surface seepage originating from the toe of the tailings dump that results in damp and a shallow water table in the people's yards; (b) stormwater runoff, in particular during the high rainfall periods; the water causes wetness and occasional ponding of water in people's yards together with the deposition of the tailings dump material (slimes) and; (c) the dust from the tailings dump during windy periods. Between 2013 and 2015, the community sought for the revision of the environmental management programmes and for the site to be rehabilitated and closed in accordance with standards of the MPRDA (Green Bond Investor Report, 2015). An order was granted in favour of the Davidsonville community members, in which the City of Johannesburg, together with the Department of Mineral and Energy Affairs, were required to reduce dust and control water pollution.

2.4.3. Case study 3: Tudor Shaft

Tudor Shaft community (Figure 2-11) is an informal settlement located on a dormant radioactive gold TSF. The Tudor Shaft community is said to consist of about 2000 residents that continue to live in shacks which are on top of an un-rehabilitated gold TSF. The informal settlement was created when the local government was relocating hundreds of people from another informal settlement a few kilometres away in 1996. According to the soil sample analysis that was acquired by the Federation for a Sustainable Environment, the soil in this area contained elevated levels of aluminium, arsenic, cadmium, cobalt, copper, mercury, manganese, nickel, zinc, and uranium. In 2011 it was established that the radiation levels were 15 times higher than the regulated levels, and this was confirmed by the National Nuclear Regulator of South Africa. Thus, it was recommended that the community should be relocated with immediate effect. A decision was taken by the Parliament to relocate the community in 2011. However, by 2013 the majority of the community still lived there. In 2017, more than 300 families were moved to Kagiso Extension 13, Krugersdorp (Maregele and Gontsana, 2017).



Figure 2- 11: Tudor Shaft Informal Settlement (source: <http://earthlife.org.za>).

2.5. Interventions by government and mining companies to mitigate environmental and social impacts

In order to mitigate environmental and social impacts that are associated with gold mine waste, the South African government has initiated interventions through laws and policies, while the mining companies have come up with projects for mitigating the environmental impacts and adhering to the environmental laws and policies.

2.5.1. Interventions to mitigate environmental and social impacts by the South African government

Environmental issues have become increasingly important and understood since the 1980s (Scott, 1995). However, South Africa had little legislation that explicitly dealt with environmental protection from mining impacts prior to 1991. The main Acts controlling the design, construction and operation of TSFs prior to 1998 were the Mines and Works Act (Act 27 of 1956), the Atmospheric Pollution Prevention Act (Act 45 of 1965), the Water Act (Act 54 of 1956, amended from time to time), the Health Act (Act 63 of 1977) and the Soil Conservation Act (Act 54 of 1956). The Water Act (as amended

by Act No. 96 of 1984) was used to classify a tailings dam structure on the basis of size and hazard potential. However, a Government Notice in 1986 exempted the mines from the provisions of the regulations (except regulation 15 regarding registration) for a period of 5 years. This was subsequently extended in 1991 for a further period of two years, and in 1993 for a further period of exemption of two years (Vermeulen, 2001). Permits regarding slimes dams had to be acquired from the Department of Mineral and Energy Affairs in terms of section 8(1)(a) and section 6B/4(2) of the Physical Planning Act (Act 88 of 1967), as well as from the Department of Water Affairs in terms of section 12.21 and section 30(5) of the Water Act, but no licence or permit was required to operate gold TSFs. Furthermore, in order to minimize environmental degradation, an environmental impact assessment was required as a formal approach to assess the effects of the project on the environment in the most cost-effective manner. In order to prevent dust pollution, the proclamation of the Atmospheric Pollution Prevention Act 45 (1965) was amended in 1973 (Weiersbye et al., 2006). Wind and water erosion of TSFs as, recommended by the Chamber of Mines (now known as Minerals Council South Africa), was controlled by the most practical means possible, using the Best Available Technology Not Entailing Excessive Cost (BATNEEC) concept (Weiersbye et al., 2006). Thus, erosion control comprised covering the surface of TSFs with waste rock or vegetation, with the 'grassing' still considered as the most effective way of reducing dust by the mining industry (Weiersbye et al., 2006).

In order to combat the previous environmental and human issues of the past governments, South Africa has adopted a multi-layered framework of human rights laws and environmental laws on both a national and international level. At national level, there is a detailed Bill of Rights in the Constitution of 1996 that incorporates a right to environmental health and socio-economic rights; at the continental level, it has endorsed the Banjul Charter (African Charter on Human and People's Rights), and at the international level, it has adopted the International Covenant on Civil and Political Rights (ICCPR) and International Covenant on Economic, Social and Cultural Rights (ICESCR). The right to environmental health has been elevated to a basic human right according to section 24 of the Constitution of South Africa Act 108 of 1996. Moreover, a series of Acts have been compiled and publicised to prioritise environmental pollution since 1998. The following subsections provide a brief overview of some of the prescribed environmental regulations and Human Rights Framework that South Africa has adopted:

Section 24 of the Constitution of the Republic of South Africa of 1996 states that everyone has the right: (a) To an environment that is not harmful to their health or well-being; and (b) To have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that (i) prevent pollution and ecological degradation; (ii) promote

conservation; and (iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development’.

The South African legislation and guidelines on environmental management and air quality emission standards pertaining to inter alia construction and operation activities are:

- Health Act, No 61 of 2003;
- Environmental Conservation Act, No 73 of 1989;
- Constitution of the Republic of South Africa Act, No108 of 1996;
- The National Environmental Management Act, Air Quality Act (NEMAQA) (Act No. 39 of 2004).
- The South African National Standard 1929 of 2005, Ambient Air Quality – Limits for common pollutants.

The National Environmental Management: Air Quality Act (no. 39 of 2004) regulate air quality standards. Air quality legislation sets national standards to many different air pollutants. These standards refer to, among others, PM₁₀, PM_{2.5} as well as dustfall rates. The regulated standards set a dustfall limit of 600 mg/m²/day for residential areas and 1200 mg/m²/day, averaged over a 30-day period, for non-residential areas. These standards allow for three exceedances within any year but not in sequential months. Since the acceptance of these standards into law, a number of regulations have also been published. These include:

- GN 1210: The National Ambient Air Quality Standards; from Government Gazette 32816, 24 Dec. 2009.
- GN 486: National Ambient Air Quality Standard for Particulate Matter with Aerodynamic Diameter Less than 2.5 µm (PM_{2.5}); Government Gazette 35463, 29 June 2012.
- GN R827: National Dust Control Regulations; Government Gazette 36974, 1 Nov. 2013.
- GN 893: Listed Activities and Associated Minimum Emission Standards; Government Gazette 37054, 22 Nov. 2013.
- GN 893: List of activities which result in atmospheric emissions which have or may have a significant detrimental effect on the environment, including health, social conditions, economic conditions, ecological conditions or cultural heritage.

With regards to the above, Department of Environment, Fisheries and Forestry (DEFF) has set the current ambient 24 h PM₁₀ limit at 75 µgm³ and the current 24 h PM_{2.5} limit at 40 µgm³, which will

further be reduced to 25 μgm^3 in the year 2030. Currently, there are no established ambient South African limits for respirable PM_{10} levels (Andraos et al., 2019). Furthermore, according to the Gauteng Department of Agriculture, Conservation and Environment (GDACE) Air Quality Management Plan report, windblown dust from TSFs has been identified as one of the six major problems along with climate change and energy, domestic fuel burning, industrial emissions, noise pollution, and vehicle tailpipe emissions (Liebenberg-Enslin and Hurt, 2009). The Health Act No. 61 of 2003 gives provision for environmental health investigations. According to point 83 of the Health Act No. 61, environmental health investigations must be done should there be any environmental condition that (a) constitutes a violation of the right contained in section 24(a) of the Constitution (b) constitutes pollution detrimental to health; (c) is likely to cause a health nuisance; or (d) constitutes a health nuisance. Secondly, should the investigations reveal any of the mentioned conditions, the health officer(s) must then determine the identity of the person responsible for such condition and issue a compliance notice in order for them to take appropriate corrective measures in minimising, removing and rectifying such condition (Government Gazette, 2004).

Section 28 of the National Environmental Management Act (107 of 1998) which encompasses the duty of care and remediation of environmental damage states that 'every person who causes, has caused or may cause significant pollution or degradation of the environment must take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring, or in so far as such harm to the environment is authorised by law or cannot be reasonably avoided or stopped, to minimise and rectify such pollution or degradation of the environment'. However, there is no clear definition for significant pollution from this environmental law. Prevention and remedying effects of pollution have been set out in section 19 of the National Water Act (36 of 1998), which seek for the owner of land, a person in control of land or a person who occupies or uses the land on which any activity or process is or was performed or undertaken or any other situation exists which causes, has caused or is likely to cause pollution of a water resource, to take all reasonable measures to prevent any such pollution from occurring, continuing or recurring. These Acts all have relevance to mining operations. For instance, the National Water Act has been highly influential in addressing AMD concerns in the Klerksdorp-Orkney-Stilfontein-Hartebeesfontein gold mining region (IHRC, 2016). On the other hand, the National Environmental Management Amendment Act (46 of 2003) enables the Environmental Management Inspectors (EMIs) or 'Green Scorpions' unit to probe environmental violations. Furthermore, the new regulatory framework for water usage renders industry accountable for the cost of water used, and polluted, as a result of operations, rehabilitation and mine waste as stated in the Waste Discharge Charge System of the Department of Water Affairs and Forestry (Weiersbye et al., 2006). This environmental legislation means that new and different,

sustainable and cost-effective methods of containing pollution from TSFs have to be established.

There are also specific laws and policies that the South African government have put into place to deal with mining pollution. Section 38 of the Mineral and Petroleum Resources Development Act (MPDRA of 2002) and its Regulations (GN R527 in Government Gazette 26275 of 23 April 2004) have been published to control the minerals and petroleum industry with regards to constitutional obligations. The MPRDA seeks to safeguard sustainable development of mineral resources, justifiable access to the benefits, better environmental protection, and includes provisions for mine closure. The MPRDA (28 of 2002) prescribes that 'in accordance with applicable legislative requirements for mine closure, the holder of a mining right must ensure that: (i) the closure of a mining operation incorporates a process which must start at the commencement of the operation and continue throughout the life of the operation; and (ii) the land is rehabilitated, as far as is practicable, to its natural state, or to a predetermined and agreed standard or land use which conforms to the concept of sustainable development'. Until fairly recently, mining waste in South Africa was regulated under the Mineral and Petroleum Resources Development Act 28 of 2002 (MPRDA). With effect from 24 July 2015, the establishment and reclamation of mine dumps and stockpiles of similar waste from or incidental to a mining operation, must comply with the new regulations regarding the planning and management of residue stockpiles and residue deposits from a prospecting, mining, exploration or production operation (Mining Residue Regulations) published under the National Environmental Management: Waste Act 59 of 2008 (NEM: WA).

Despite the introduction of new legislation, the legal framework regulating mining's social and environmental responsibilities, there is a perception that the enforcement of these regulations by government departments has not been effective (Durand, 2012; IHRC, 2016). Thus, mining companies have continued to exploit weaknesses in the regulatory environment, and the practice of deflecting social and environmental costs continues (Bobbins, 2005; Adler et al., 2007). Moreover, in the East Rand, Central Rand, and West Rand, most of the gold mines were either abandoned or liquidated before their environmental and health impacts became evident (Durand, 2012). Others that were remaining have either amalgamated into larger companies (e.g. amalgamation of Mintails and Blyvooruitzicht Gold Mining Company) or had changes in ownership (e.g. Sibanye Gold). Hence it is difficult to enforce compliance by the government/DMR (SAHRC, 2016).

Currently there is inadequate provision for the rehabilitation of TSFs by the government. As an example, the Blyvooruitzicht Mine in Carletonville left behind an unrehabilitated footprint which includes TSFs without vegetation, dust fallout, as well as toxic and radioactive water, soil, and infrastructure. The total rehabilitation amount was estimated at R890 million, 22 times more than

the R44 million DMR rehabilitation fund amount. This DMR rehabilitation amount suggests that there is inadequate financial provision to address rehabilitation damage to the environment. This, therefore, bridges the undertaking provided for in the EMP that the environment would be left 'geologically and geophysically stable and would not pose an economic, social or environmental liability to the local community and the state, now or in the future' (SAHRC, 2016). According to the SAHRC (2016) the DMR has not taken adequate steps to secure monetary provision for rehabilitating the damage on the environment and water resources, and that there is an immediate requirement for all Environmental Impact Assessments (EIAs) and Environmental Management Programmes (EMPs) to clearly detail land quality and potential post-closure land use.

Widespread contamination by the TSFs has raised concerns under the rights to health, a healthy environment, water, and housing, while inadequate community engagement has interfered with the rights to receive information and participate in decision-making (Bench Marks Foundation, 2017). Communities have complained to both the government and the industry which has not provided sufficient cautions about the potential risks of mining activities and remedial measures (IHRC, 2016). In addition, epidemiological studies regarding the effects of mining contamination on human health have not been conducted, despite the documentation and studies about contamination levels of the TSFs and surrounding areas (IHRC, 2016). The South African Human Rights Commission, in its report on Mining Communities, found that it is unacceptable for mining companies to not provide detailed and sufficient information to enable communities and local governments to clearly understand how land can be used post mine closure (SAHRC, 2016). Following the SAHRC Report on Mining Communities, an Inter-Ministerial Committee (IMC) on revitalisation of Distressed Mining Communities (DMC), which is chaired by Minister Nkosazana Dlamini Zuma, was established. The IMC is mandated to achieve integrated and sustainable human settlements, improve the living and working conditions of mineworkers and health of mining communities, and advance the socio-economic development of mining towns by implementation of recommendations of the SAHRC's Report on Mining Communities. Numerous Water Research Commission projects were also conducted to develop solutions for environmental impacts that arise from TSFs.

The buffer zone (500 m) around the TSFs as prescribed by the mining regulations have not been adhered to as with the case study 2 and 3. Even with the latest data on the emerging increase in health risks for residents, the housing developments have been continuing into the 500 m buffer zone, as in the earliest aerial photographic images examined by Kneen et al. (2015). According to Kneen et al. (2015), since 1952, the housing development has experienced a growth of 14 % per annum, resulting in an overall growth of approximately 700 %. Housing patterns and dynamics have

been shaped by the historical politics, with subsequent occupation of vacant land that had constituted the safety 500 m buffer zone proximate to both active and dormant TSFs. Housing developments have continued to sprout few meters from the edges of the TSFs. For over half a century (since 1952), the residents of Johannesburg have been living in the shadow of TSFs (Kneen et al., 2015). Similarly, in the Roodepoort area (West Rand District), by 1976, the encroachment of residential development towards the boundaries of the TSFs began. Although development areas within TSF buffer zones remained minor through 1991, it increased after 1991, due to the scarcity of open land near to the city centre and the shifting political climate. The building of government-financed housing developments (also known as RDP houses) often encroached on the TSFs buffer zones (Kneen et al., 2015). The residential development in Roodepoort area has grown from zero in 1952 to 0.63 km² in 1976 and 8.46 km² in 2002 (Kneen et al., 2015). This has increased the likelihood of people being exposed to health hazards and subjected to environmental consequences of dust pollution from the TSFs (Ojelede et al., 2012). For decades, the encroachment of residential houses onto land close to TSFs (Table 2-5) has continued unrestricted, increasing human exposure to windblown dust and metal pollution from the TSFs.

Table 2 - 5: Households and residential areas around tailings storage facilities during 2001 and 2011 with estimates of population for the City of Johannesburg (Kneen et al., 2015).

Buffer distance (m)	Number of households (2001)	Population estimate (2001)	Number of households (2011)	Population estimate (2011)
500	26 232	80 700	22 370	71 600
500 - 1000	24 809	82 600	39 524	126 500
1000 - 1500	21 597	69 300	36 192	115 800
1500 - 2000	16 575	52 000	31 510	100 800
2000 - 2500	16 144	51 700	28 445	91 000
2500 - 3000	16 489	53 900	24 952	79 800
Grand total	121 846	390 200	182 993	585 500

2.5.2. Interventions to mitigate environmental and social impacts by the mining companies

As stated in the first sections of this chapter, South Africa's gold mining industry has long reached maturity. During this time, little was done to cater for decades of environmental negligence such as setting sufficient budgets aside for environmental rehabilitation, mine closure, and assets impairment (Jeffery, 2018). The subsections below provide details of some of the recent initiatives

by mining companies aimed at treating defunct gold tailings dumps and their impacts on the environment and society in general. The mining industry is involved in major initiatives to reclaim gold tailings facilities containing recoverable gold resources and rehabilitate defunct tailings facilities. However, access to much of the work performed on behalf of the mining companies is restricted.

2.5.2.1. TSFs reclamation

According to GCRO (2018), the increasing environmental regulation since the 1990s has led to numerous efforts to control remaining TSFs and their toxic dust through greening (phytoremediation). On the other hand, some mining companies such as DRDGold and AngloGoldAshanti have begun to reclaim the gold TSFs by reprocessing mining waste in search of new profits. The objective of TSFs reclamation is to recover residual gold from the tailings and/or uranium, as well as to oxidize the sulphides in order to prevent long term environmental liabilities associated with acid mine drainage. The reclamation of mining gold TSFs has resulted in the disappearance of once familiar landmarks, for example the 'mine dump' on which the popular Top Star Drive-In used to be located. The reclamation of the gold TSFs is one way of alleviating their negative environmental impacts while creating environmental, social and economic assets for the region they are located in. For example, DRDGold (2016) reported that during 2015 – 2016, the National Nuclear Regulator cleared 255 ha of sterilised mining land previously occupied by TSFs for development within the inner cities of Johannesburg and Ekurhuleni. The reclamation of the TSFs has impacts on air and water quality, therefore, DRDGold has placed vast monitoring systems across Johannesburg and Ekurhuleni. There is measuring of 115 sites for dust fallout and measuring of 76 sites for groundwater pollution (DRDGold, 2016). DRDGold environmental and social impact is to restore the environment, unlock land, long-term enhancement of quality of life in areas of impact through environmental containment, environmental clean-up, education and poverty alleviation and empowerment (DRDGold, 2016).

As much as there is some success with the reclamation of old gold TSFs, there has been some failures as well. The Mintails Group had proposed reclamation of defunct gold tailings dumps spanning Krugersdorp and Randfontein as a way to solve environmental and sustainable development issues within the West Rand district (Bega, 2019). Heavy wind still blows over the West Rand with clouds of dust swirling from clusters of barren mine dumps towering over both sides of Main Reef Road. The reclaimed tailings dump structure collapsed from ongoing spillages during Mintails' operations. Mintails Group, which was listed on the Australian Stock Exchange as a gold mining and tailings processing company, went into business rescue in October 2015 and was liquidated in September 2018, leaving what has now been termed one of the "worst environmental catastrophes". Mintails

Group has an unfunded environmental liability of R485 million, but only around R25 million financial provision in its environmental rehabilitation funds. It reclaimed only the profitable sections of the dumps, failing to rehabilitate any footprints. Several polluted, highly contaminated dams and open pits are easily accessible to school children, churchgoers and, community members. These dams are toxic and potentially radioactive (Bega, 2019). In terms of the Mineral and Petroleum Resources Development Act, No. 28 of 2002, the community have to play a proactive part in the process of land use. According to van Tonder et al. (2008), determining of end-state and land-use on current and former mining land cannot be done without the full involvement of all stakeholders, that is, the industry, the local community, local and regional government, and all regulators.

2.5.2.2. Super dumps

The reprocessing of the gold TSFs for its residual gold has not solved the problems associated with the TSFs because it has mainly focused on Au recovery excluding metals and metalloids (GCRO, 2018). While a fair amount of land is freed for other land uses, new waste (that is, re-mined tailings) is produced in the process of re-mining of the old TSFs. The re-mined tailings are usually deposited in a single large TSFs commonly known as 'super dump'. According to GCRO (2018), from the early 2000s, the consolidation of re-mined tailings into a limited number of 'super dumps' has been a priority. In Johannesburg through 'Project Hloekisa', collaborations were formed between several gold recovery companies, different landowners and multiple government agencies to cooperatively channel waste to the Nasrec and Ergo super dumps. The Johannesburg City through this consolidation seemingly has a potential to release approximately 16 000 ha of land. However, this project depends on vast resources of energy and water for the tailings recovery, huge tracts of pipeline to the 'super dumps', and a suitably high gold price to maintain the lot, hence it is uncertain how far along this 'Project Hloekisa' has come (GCRO, 2018).

In 2009 two mining companies, Gold Fields Limited and Rand Uranium, announced that they have earmarked a massive 5 km² stretch of fertile farmland nestled behind a ridge close to the N12 between Johannesburg and Potchefstroom for two super dumps (WISE, 2019). This has sparked an outcry from the farmers describing that the loss of this fertile land for farming will be catastrophic and thus they are opposing the reconstruction of these super dumps. The affected farmers state that the super dumps may contaminate groundwater and cause major dust storms (WISE, 2019). Aside, from land sterilisation concerns, the geology of the target area consists of geotechnically unstable/porous dolomites and may pose a hazard to residential areas located near the identified site (Ryan, 2009). According to the environmental requirements, the 'super dump' must be deposited

on impervious geological formations in order to prevent pollution of the groundwater by seepage of water that might be containing contaminants such as sulphur and cyanide from the dump.

2.5.2.3. Remediation of tailings dumps using stabilisation and revegetation

Remediation of gold tailings through revegetation is now a common practice as part of the remediation strategies that are aimed at establishing a permanent plant cover for stabilization and aesthetic reasons (Ye et al., 2002). Vegetation of tailings also offers a benefit of reducing air pollution and the transportation of toxic materials into nearby watercourses. The efficiency of this type of vegetation is determined by the plants ability to survive and thrive in gold tailings that contain elevated levels of sulphur and metals, as well as the ability of seedlings to survive and rapidly develop both root and shoot biomass with a minimum of substrate amendment. Through biological and physical processes, the vegetation may improve the qualities of the tailings (Ye et al., 2002).

DRDGold has engaged on vegetation programmes for gold tailings facilities. According to the media site visit report the following sites have been vegetated and with some still in progress status: Crown, Rooikraal tailings facilities: 283.76 ha vegetated in five years and the Crown slope currently vegetated at the rate of 2 ha/month (DRDGold, 2016). Table 2-6 summarizes the vegetation programmes.

Table 2 - 6: Vegetation programmes by DRDGold (DRDGold, 2016)

Top surfaces				
TSF	Total area	Complete area	% of area to date	Comments
Mooifontein	30 ha	30 ha	100 %	Completed
GMTS	43ha	43 ha	100 %	Completed
Diepkloof	19,76 ha	19,76 ha	100 %	Completed
Homestead	26 ha	26 ha	100 %	Completed
Rooikraal	85 ha	85 ha	100 %	Completed
Slide slopes				
TSF	Total area	Complete area	% of area to date	Comments
Mooifontein	75,4 ha	21,8 ha	29 %	Expected completion 2020
GMTS	108,9 ha	33 ha	30,3 %	Currently vegetating
Diepkloof/Homestead	100 ha	25 ha	25 %	Expected completion 2022

Through side slope vegetation, hardy tree species were planted with under irrigation, thus preventing erosion and increased biodiversity. Top vegetation primarily involved dust netting with vegetation (Figure 2-12).

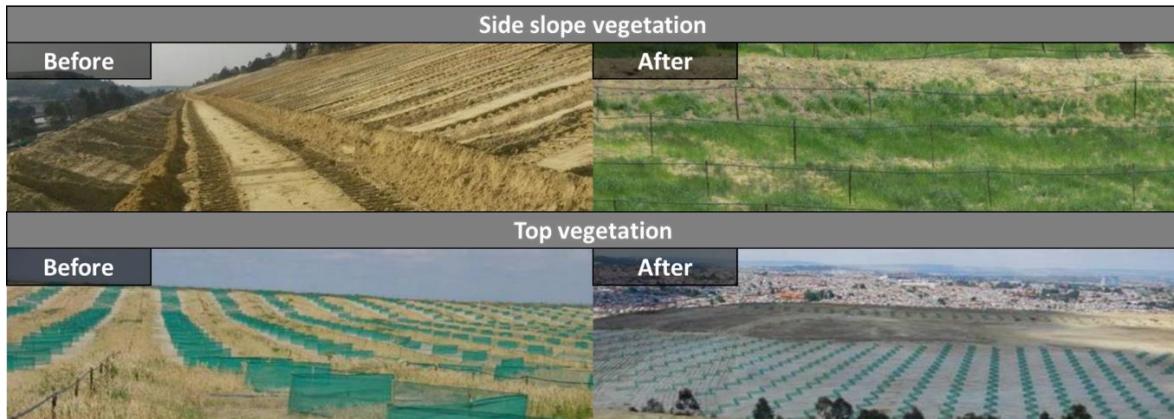


Figure 2- 12: Vegetation of the gold tailings facilities (DRDGold, 2016).

2.6. Summary and synthesis

In South Africa, gold mining has initiated an unusually rapid population growth, inflows of migrant labourers that led to the increase of provisional houses, the formation of mining camps, and eventually towns and cities which have continued to grow and develop. Geological prospecting, mining excavations, processing of a range of ore minerals, and the reclamation of gold tailings continue to make the Witwatersrand mining a major regional industry, ranking 7th in the world. Even with the closing of most of the gold mines, some of the surrounding settlements and towns do not become ghost towns. Thus, the Witwatersrand region is still a vibrant economic hub.

During gold mining and mineral processing stages, large waste material is generated, and tailings dumps or storage facilities (TSFs) have become a major feature of the Witwatersrand landscape. The material contained in these dumps consists of quartz, mica, pyrite, gold, carbonates, oxides and metals (As, Cd, Pb, U, Cr) that are above crustal averages. Literature reports have shown that these dumps are a major cause of air, water and soil pollution in the region, with this pollution spreading far beyond the TSF sites. In particular, the oxidation of pyrite in the tailings gives rise to AMD, which increases the metal load in the watercourses and soils, causing a knock-on effect on the ecosystems. Furthermore, sporadic dust events with ambient particulate matter (PM₁₀) occur when wind blows the tailings material. Impacts of gold TSFs extend beyond environmental impacts, and affect the health and the quality of life and livelihood of human beings living in their vicinity, with tailings dumps having become a major concern to the communities, mining industry, and the government. Studies have shown that dust from the old TSFs is considered a nuisance.

This is particularly the case for communities in areas where settlement has occurred on land close to the mine sites and TSFs, such as Davidsonville, Tudor Shaft, and Riverlea. Even where townships and

informal settlements lie outside of the buffer zones, they often occur directly downwind and downstream from defunct mines and waste dumps. As a result, there is an increase in human exposure to increasingly hazardous inhalable dust from the tailings dumps.

This exposure has been a major cause of conflict between communities, mining houses, and government in the Witwatersrand area. While the government has implemented laws to mitigate the impacts of pollution by mine waste, pollution by the TSFs has raised concerns under the rights to health, a healthy environment, water, and housing, while inadequate community engagement has interfered with the rights to receive information and participate in decision-making. Mining companies have also been involved in efforts to control environmental pollution arising from gold TSFs through reclamation, revegetation of gold TSFs, and super dumps. However, it should be noted that reclamation is primarily aimed at recovering value and, although this does offer an opportunity to better re-dispose of tailings material in better designed dumps, opportunities to completely remove TSFs by repurposing tailings have not yet been explored. Furthermore, the process of reprocessing is, in itself, very disruptive and associated with a number of environmental impacts.

CHAPTER 3

STAKEHOLDER PERCEPTIONS AND EXPERIENCES: A DAVIDSONVILLE CASE STUDY

From chapter 2, it was noted that defunct gold tailings facilities are a source of environmental and social impacts. From the case studies, it was evident that there are some conflicts that exists between the different stakeholders. As set out in chapter 1, the aim of the semi-structured interviews was to (a) establish perceptions, experiences and expectations about the socio-environmental impacts caused by defunct gold tailings in order to address the relationships value chain between the community layman, mining companies, the government, non-profit organisations, and subject experts, and; (b) analyse the extent to which current community concerns and expectations have been addressed by responsible parties (for example, gold mining companies and the government). This chapter presents the results from the semi-structured interviews. Based on the information gathered, the stakeholders' perceptions and experiences are given in this chapter. The following topics will be covered in this chapter: (a) Methodology (section 3.1); (b) Results and discussion (section 3.2) and; (c) Summary and synthesis (section 3.3).

3.1. Methodology

The main focus of the study is Davidsonville which is situated in the Central Rand goldfield of the Witwatersrand Basin, ~20 km south west of Johannesburg (Figure 3-1). There is currently no active deposition/dumping of new tailings on this area; however, there are new mining interests by various small-scale gold mining companies to reclaim Princess gold tailings dump. The Princess tailings dump is surrounded by the residential settlement of Davidsonville to the north and north-west, a small-scale brick and scrap metal industry to the east and south, and nine other dormant gold tailings deposits to the south. None of the dormant tailings dumps have been rehabilitated and are often reclaimed by illegal miners.

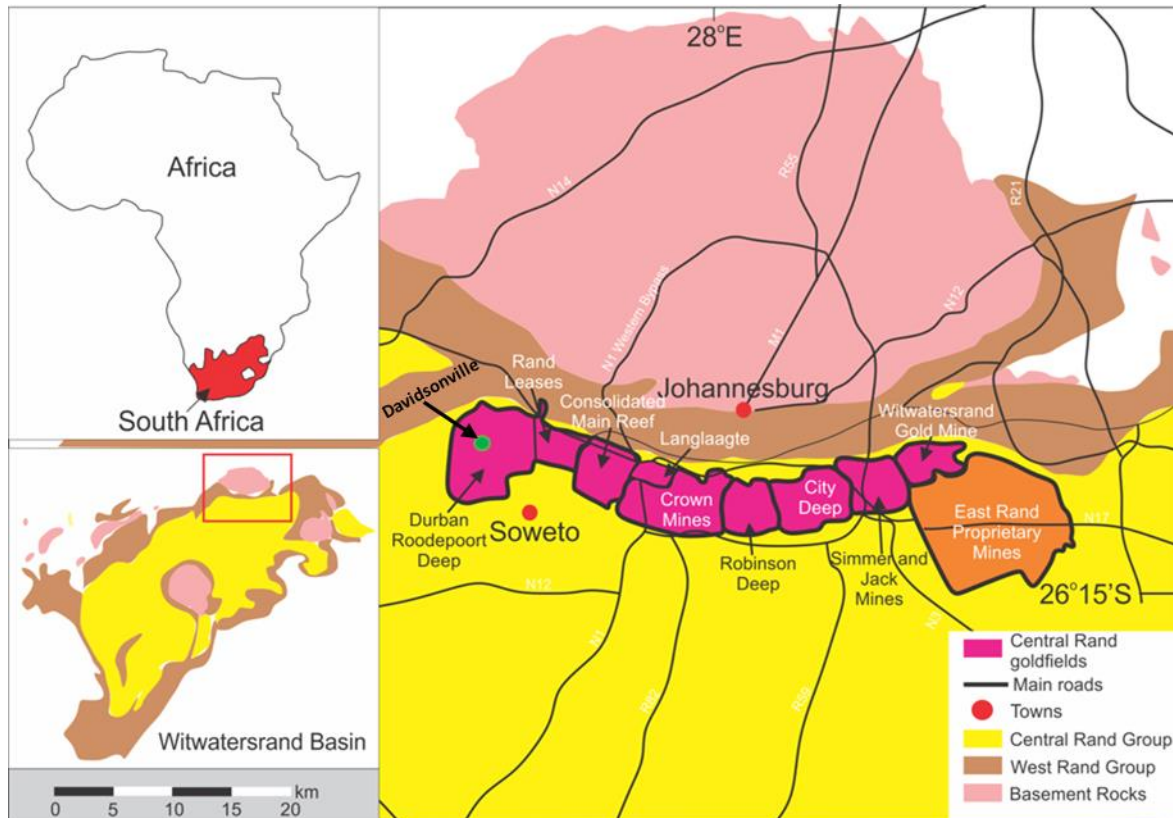


Figure 3- 1: Geological map of the Witwatersrand Basin showing the location of the Central Rand goldfields relative to Johannesburg.

Semi-structured interviews were conducted with community members from Davidsonville, members of a non-profit organisation concerned with protecting the rights of mining communities, as well as expert consultants in the area of gold mining and its environmental and social impacts. The stakeholders are all involved in some way and/or affected by impacts of defunct gold tailings dumps in Davidsonville, Johannesburg.

The interviews aimed to establish:

- (a) perceptions, experiences and expectations about the socio-environmental impacts caused by defunct gold tailings in order to address the relationships value chain between the community layman, mining companies, the government, non-profit organisations, and subject experts and;
- (b) the extent of which current community concerns and expectations have been addressed by responsible parties.

3.1.1. Description of participants

A total of 7 stakeholders were interviewed; with three being community members, three professional experts, and one representative from a civil society organisation (Table 3-1). Although

the number of participants may be relatively low, sample integrity in recruiting the participants was crucial. A sample size of 7 participants chosen in this study was based on the ‘information power’ principle (Malterud et al., 2015), that is, all the participants have extensive and relevant expertise on the gold tailings facilities site in Davidsonville, Central Rand, Johannesburg. As such, the pool of respondents can be considered to provide adequate representation of the perceptions, experiences, and expectations of communities, community support organisations, and expert consultants with respect to the socio-environmental impacts caused by defunct gold tailings in Davidsonville

Table 3 - 1: Interviewed participants

Participant ID	Organisation	Role/ Level of Expertise
Participant 1	Community	Activist in affected communities
Participant 2	Community	Activist in affected communities
Participant 3	Community	Community member
Participant 4	Non-profit organisation	Lead researcher on community impacts associated with mining
Participant 5	Non-profit organisation	CEO and environmental and human right activist in mining-affected communities
Participant 6	Environment consultancy	Considerable experience and expertise in environmental issues associated with impacts associated with the mining sector
Participant 7	Environmental and social services consultancy	CEO/Expert in environmental and social impact assessments

3.1.2. Interview process

Interviews were conducted face-to-face. A questionnaire with abstract and consent form was sent to the participants prior to the interview. This allowed the participants an opportunity to understand the aim and objectives of the study and give them a platform to ask questions before the interview. Interviews were conducted in locations which suited the participants, and were conducted individually, that is, no group interviews. Before conducting the interviews, participants signed a consent form. All the interviews were recorded. Questionnaires were used to guide face-to-face interviews. The interview questions were designed to ensure that the research aims were met and

were based on and informed by the findings from the literature study. However, the interviews were conducted in a semi-structured manner to provide an opportunity for participants to elaborate on their answers and to provide for more nuanced discussion. Different questionnaires were compiled for community members, and subject experts. The questionnaires are included in Appendix D. The face-to-face interviews were recorded and later transcribed and analysed using Microsoft Excel graphs.

3.1.3. Research Ethics

In order to ensure that the research complied with ethical practices, the questionnaire underwent an ethics review by the Engineering and Built Environment Ethics in Research Committee (EiRC) before data collection. This was done in order to ensure that (a) the participants participated voluntarily and that they were not forced to be part of the research; (b) no harm either physical or psychological was done to the participants; (c) anonymity and confidentiality of the participants is preserved and that permission obtained from the participants to share their information publicly and; (d) the participants were made aware of the project aims and objectives and that the procedure of the study is set out in a manner that the participants understand and is not deceitful. Successively, the ethics approval was granted by the EiRC as the proposed research questionnaire was found to be compliant with ethical standards. A copy of the form is available in Appendix B.

Participants were requested to sign an informed consent (Appendix C) form prior to commencement of the interview. The informed consent form was given to the participants in order to ensure that participants understood the aims and objectives of the study. Again, to ensure that participants understood the confidentiality procedures. The data collected from the interviews remains in an anonymous form, and there is no direct reference to the participants in the thesis, only the evidence is presented in a discreet form.

3.2. Results and discussion

3.2.1. Concerns on environmental and social impacts

In order to establish the stakeholders' perceptions, concerns, and understanding, section A of the interview schedule listed specific issues, that is, environmental and social impacts arising from defunct gold tailings deposits, which the participants were required to rate by their relative risk from very low (1) to very high (5) risk. The environmental impacts/risks were: air quality, water quality, soil fertility, crop productivity, health of natural ecosystems, land loss/occupation, tailings dump seepage/run-off, and tailings dump material erosion and metal contamination; and the social

impacts/risks were: human health and quality of life and livelihoods. The participants were subsequently invited to elaborate on their understandings and concerns regarding the specific environmental and social impacts ranked in the previous section (Part B). Figure 3-2 represents the ratings for the environmental and social impacts/risks. These ratings are elaborated in detail in the sections below.

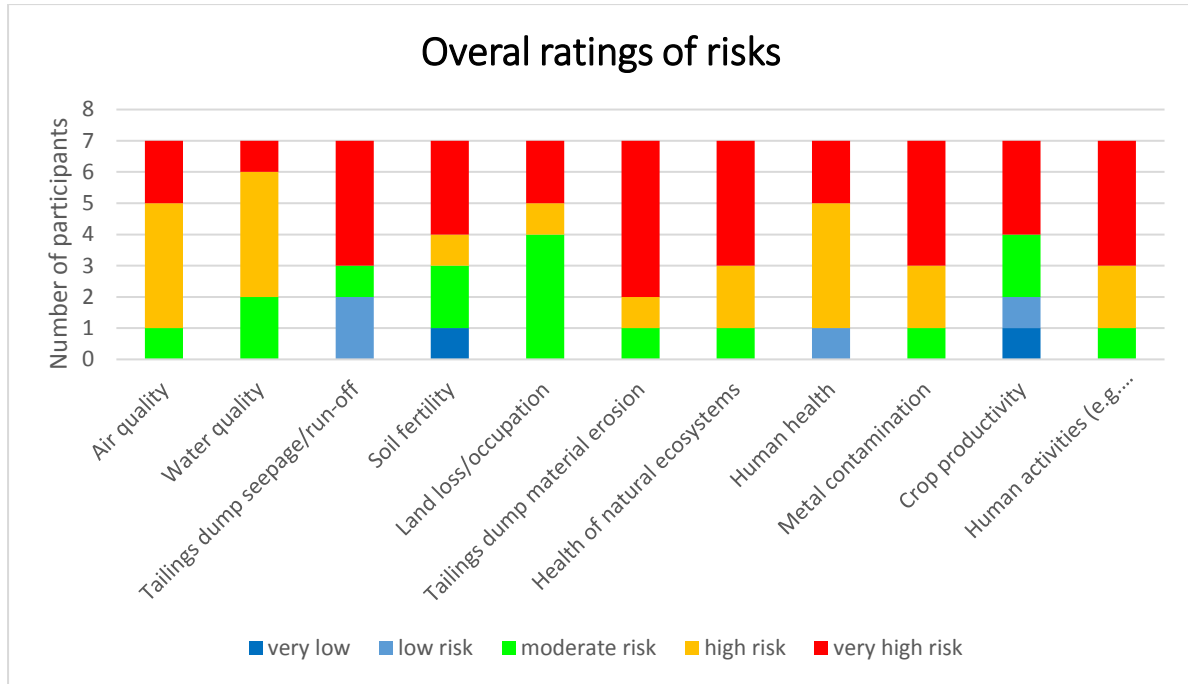


Figure 3- 2: Rating of environmental and social impacts/risks.

3.2.1.1. Air pollution

Based on the participants' rating, 6 of the 7 participants believed that the Princess tailings dump posed a high (4) to a very high (2) risk, whilst the remaining 1 of the 7 participants rated air quality as a moderate risk (Figure 3-3). Participants mentioned that this was due to the Princess tailings dump not being covered with vegetation. Community members mentioned that the air they inhale has sand from the Princess tailings dump. *"There is no fresh air, we breathe air with sand"- Participant 1; "I have the right to breathe fresh air. When there is dust blowing and eating you can taste the sand. It's like sand in your mouth" – Participant 3.*

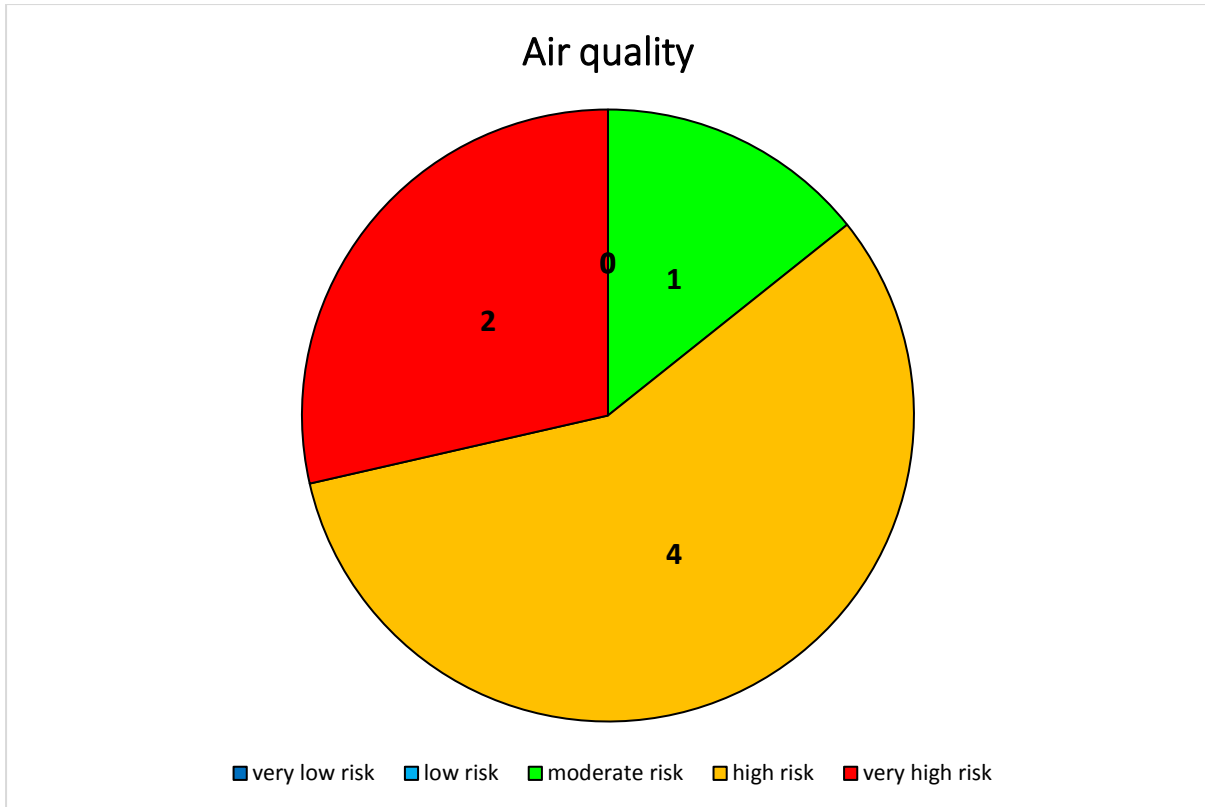


Figure 3- 3: Rating of air quality risks (numbers on graph represent number of participants).

Dust is particularly problematic in the windy season: *“The particles from the dump pollute the air. During August, it is worse.”* – **Participant 2**. **Participant 5** raised concerns regarding the presence of radioactive particles in the dust. Participants have also noted that dust related air pollution is a manageable problem and that mitigation and management interventions lower the risk/impact. *“Dust and air pollution are a manageable problem.”* – **Participant 6**; *“Mitigation and management of the impacts lower the risk”* – **Participant 5**.

3.2.1.2. Water pollution and tailings dump seepage/run-off

Based on the participants’ rating, 4 out of 7 rated water quality as a high risk, 2 as a moderate risk and 1 as a very high risk (Figure 3-4). All the community member participants reported that their potable water is not affected as Rand Water supplies it. However, it was noted that water in the nearby wetland and park is polluted and is void of aquatic life. According to the community activist and experts, the degradation of water quality is mainly attributed to Acid Mine Drainage (AMD). *“Acid mine drainage causes the degradation of water”* - **Participant 5**. Acid mine drainage is deemed to be the key in releasing the metals into the environment. *“Gold mining is associated with heavy metals Uranium, Lead, Cobalt, and Thorium”* - **Participant 5**.

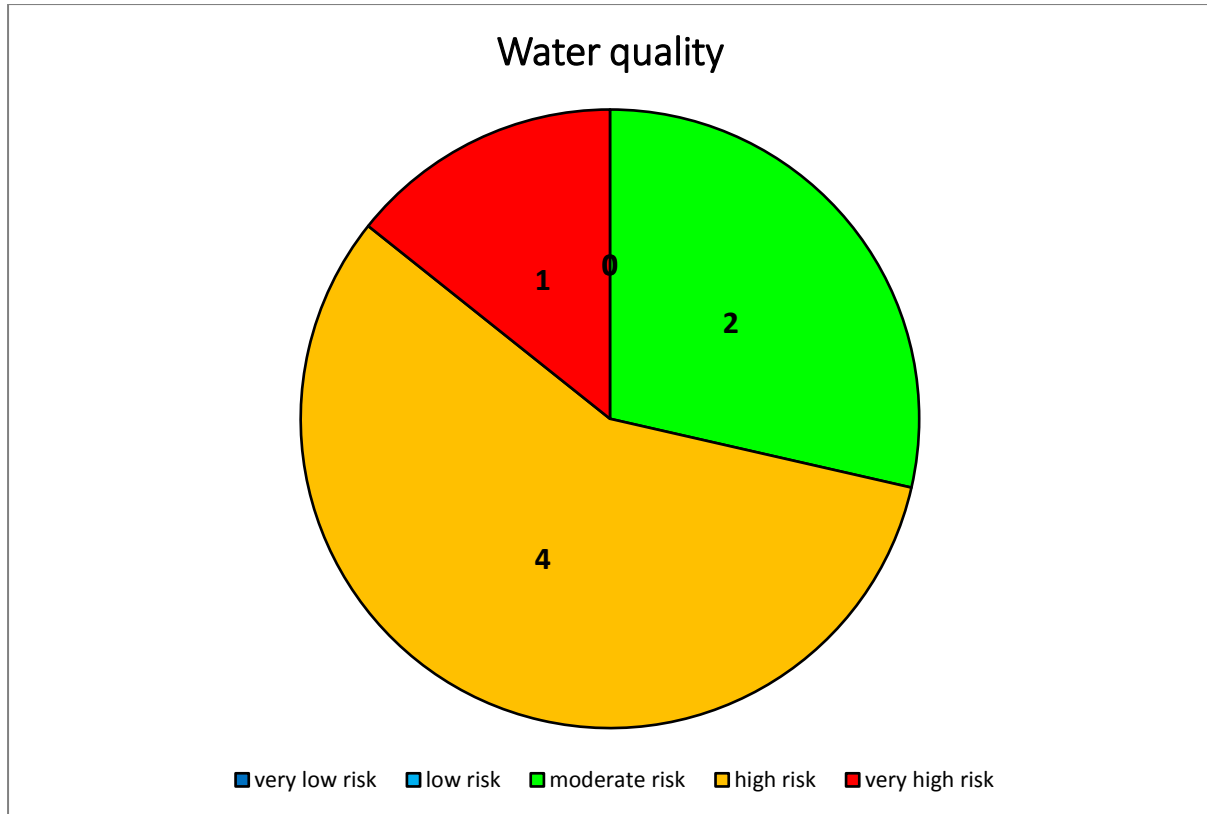


Figure 3- 4: Rating of water quality risks (numbers on graph represent number of participants).

Based on the participants' rating, 1 out of 7 rated tailings dump seepage/run-off as a low risk, 1 rated it as a moderate risk, and 5 as a very high risk (Figure 3-5). Tailings dump seepage/run-off according to the experts is managed properly when the mining is still active. However, the risks of run-off and seepage of contaminated water are higher post-closure. *"After mine closure, the mining companies monitor the mining sites for five years, however, pollution goes beyond the five years"* – **Participant 5**. Once mining has ceased, it then becomes high risk. *"About two years ago, the water came down to people's houses from the dump"* – **Participant 3**. **Participant 1** furthermore mentioned that three children died due to sinking sand; there are tailings overflow, particularly in the raining season, and that trees die due to contaminated water.

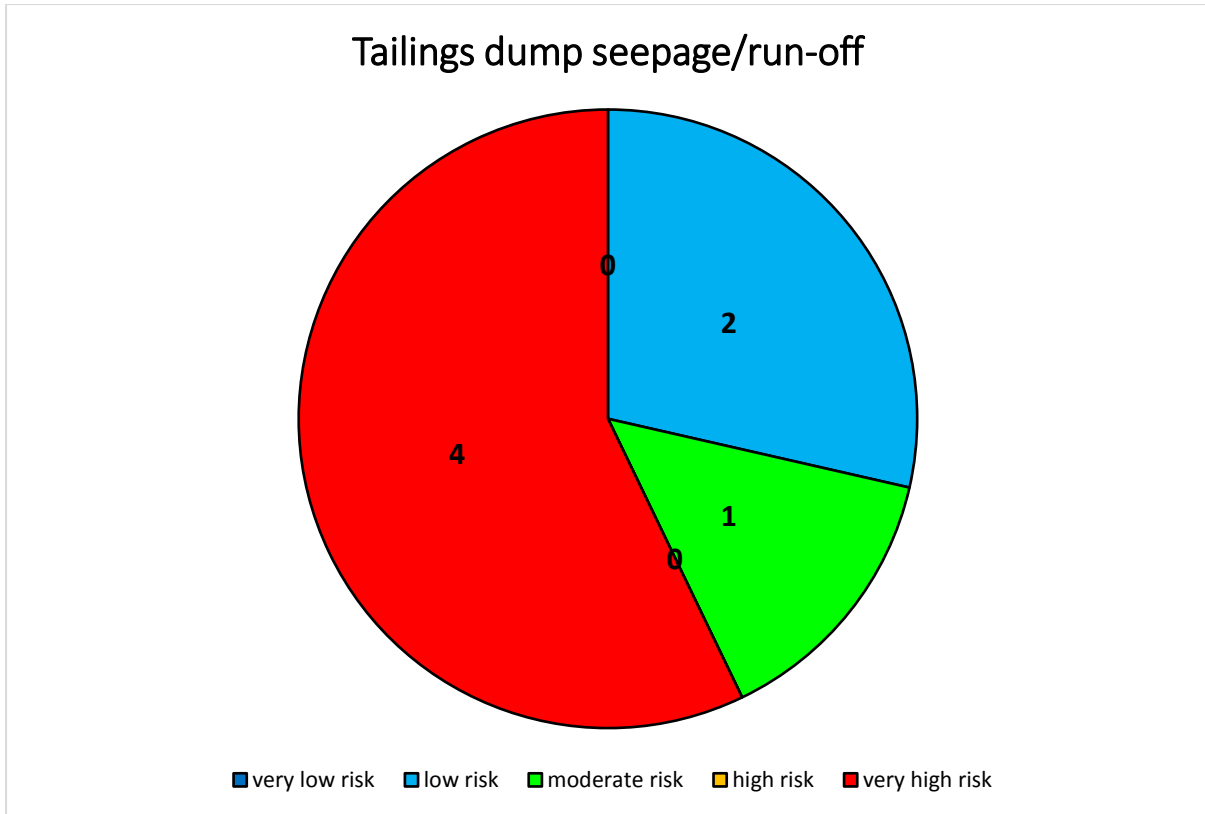


Figure 3- 5: Rating of tailings dump seepage/run-off risks (numbers on graph represent number of participants).

3.2.1.3. Soil pollution and land impacts

(i) Soil pollution/fertility

In chapter 2 section 2.2.3, it was noted that AMD leaches metals into the soil and due to the acidification of the soils, the nutrient cycle and decomposition rate in soils is negatively impacted. It is for this reason that soil pollution has been linked directly to soil fertility. The responses for soil fertility were quite diverse. Based on the participants rating, 1 out of 7 rated soil fertility as a low risk, 2 rated it as a moderate risk, 1 as a high risk and 3 as a very high risk (Figure 3-6).

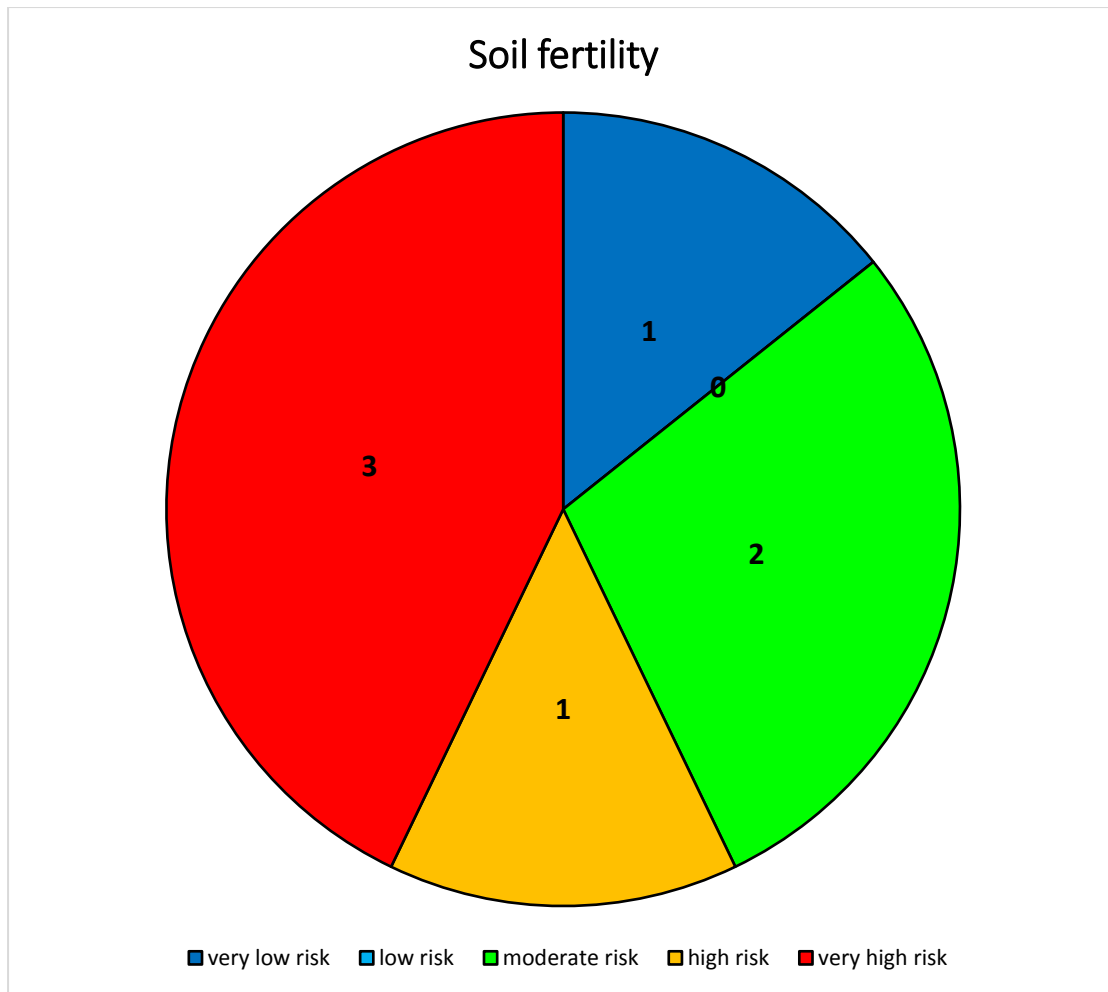


Figure 3- 6: Rating of soil fertility risks (numbers on graph represent number of participants).

(ii) Land loss/occupation

Based on the participants' rating, 4 out of 7 rated land loss/occupation as a moderate risk, 1 rated it as a high risk, and 3 as a very high risk (Figure 3-7). It was noted that the tailings dumps take up space that can be used for other land-use purposes. According to one expert (participant 4), there is a fundamental change in land-use due to tailings dumps. *"There is no room for expansion, and people live less than 50 m away from the dump"* – **Participant 1**; *"We are boxed in by the tailings dump and there is nowhere to go"* – **Participant 2**. One of the experts stated that the tailings dumps take up a lot of space, however, the defunct tailings dumps were not built on areas that were used for agriculture and other land-uses. *"The tailings take up a lot of land but the old tailings were built on space that was not taken up by agriculture and other land uses"* - **Participant 7**.

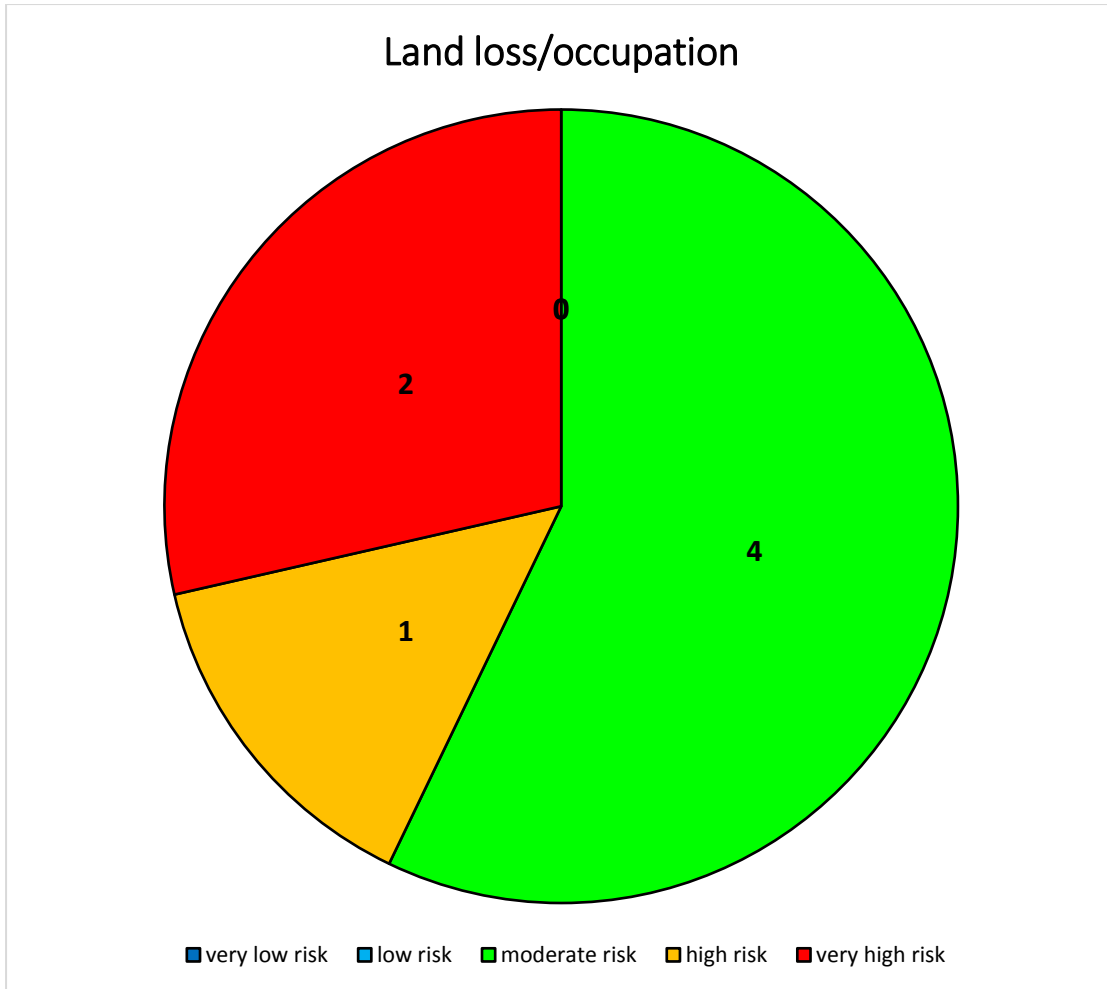


Figure 3- 7: Rating of land loss/occupation risks (numbers on graph represent number of participants).

(iii) Tailings dump material erosion

Based on the participants' rating, 1 out of 7 rated physical erosion of tailings dump material as a moderate risk, 1 rated it as a high risk, and 5 as a very high risk (Figure 3-8). Community members stated that the tailings dump material erodes into the streets and their yards (Figure 3-9). *"Look at the street there, it has the soil from the dump"* – **Participant 2**.

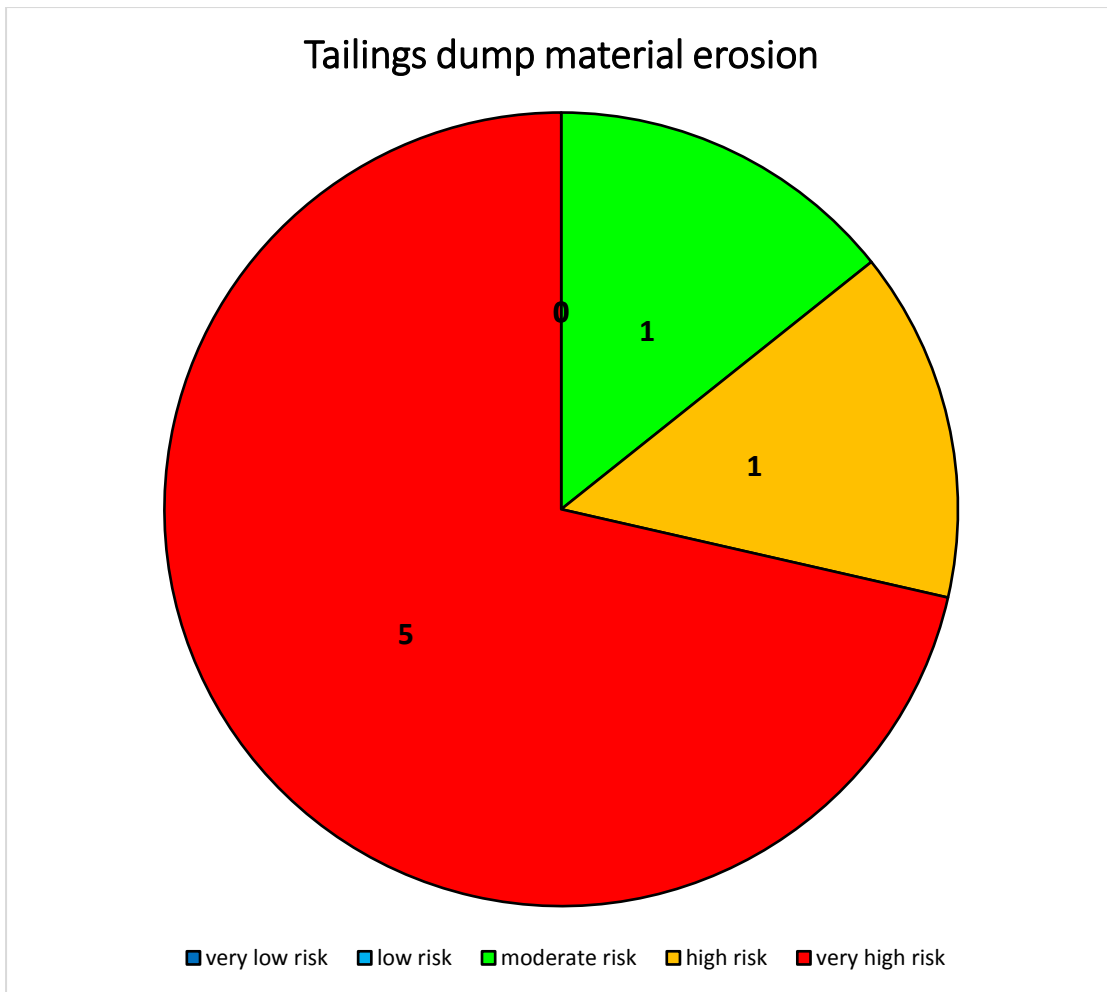


Figure 3- 8: Rating for physical erosion risks (numbers on graph represent number of participants).



Figure 3- 9: Princess tailings dump material eroded to the nearby streets.

(iv) The health of natural ecosystems

Based on the participants' rating, 1 out of 7 rated health of natural ecosystems as a moderate risk, 2 rated it as a high risk, and 4 as a very high risk (Figure 3-10). According to two experts and an environmental and human rights activist, natural ecosystems are altered by tailings dump material. The natural ecosystems cannot be restored to their natural conditions. *"You cannot restore the environment to its pre-mining condition"* – **Participant 5**. *"Mining and its waste are 100 % destructive, there is a fundamental change in land-use"* – **Participant 4**.

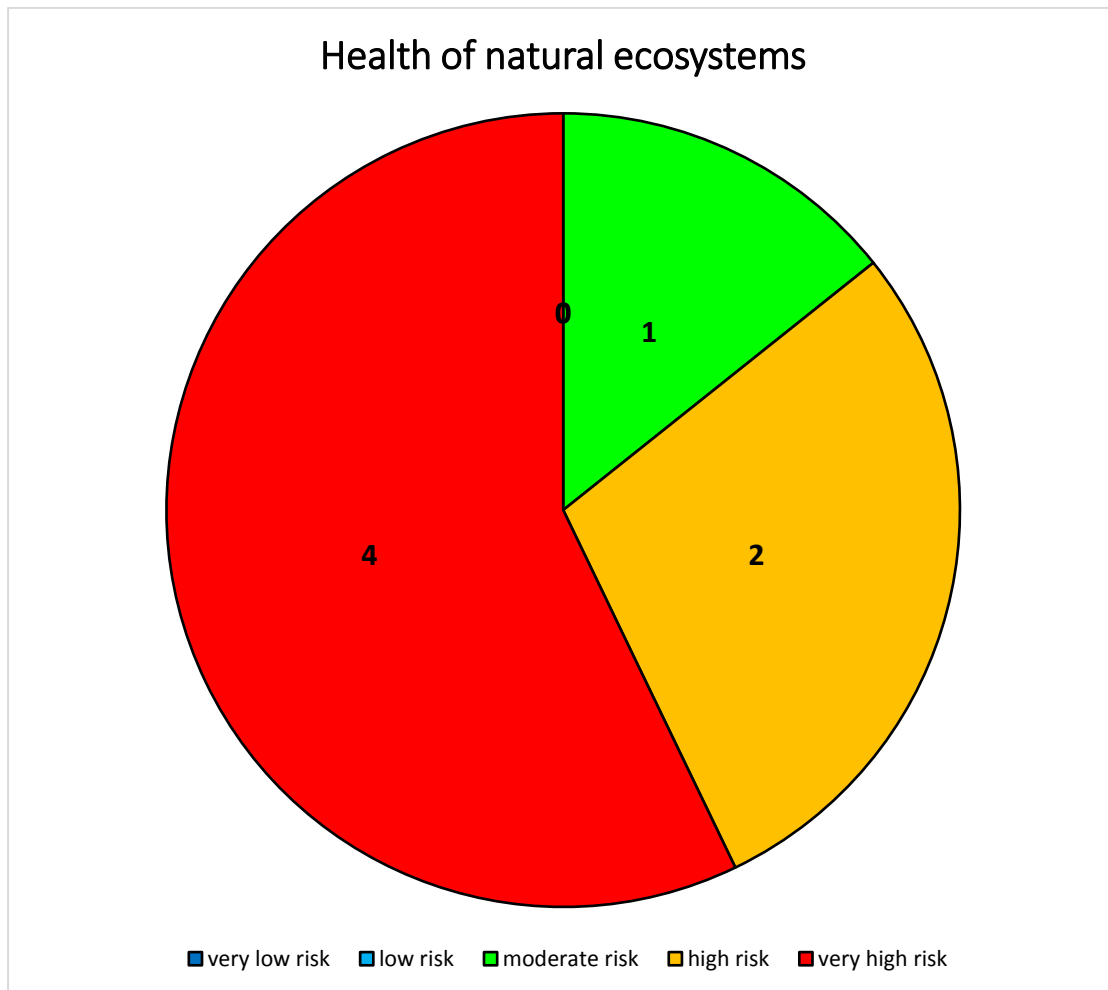


Figure 3- 10: Rating of natural ecosystems health risks (numbers on graph represent number of participants).

3.2.1.4. Human health and livelihoods

(i) Human health

Based on the participants rating, 1 out of 7 rated human health as a low risk, 4 rated it as a high risk, and 2 as a very high risk (Figure 3-11). On the one hand, community members believe that the tailings dump material is causing them to become sick. **Participant 2** said, *"Yes these risks and impacts affect*

our health due to cancer, skin rashes, and vision/eyesight problems, and reduce life expectancy”. The community members mentioned that their local clinic is full of people suffering from respiratory and skin diseases. “We have to be educated about the mine dumps, especially by the government. The government doesn’t care. These things (mine dumps), they cause cancer” – **Participant 3**. The community members, in particular, have expressed that their life expectancy has decreased due to the tailings dump as compared to members of the same demographics as them in other areas without the tailings dump. Participant 2 stated that “Life expectancy is less than 60 years and water that gathers in the park which kids use for swimming, skin and hair growth is affected”. Subject experts cautioned that human health is not being assessed and there are few health studies to show that community members are becoming sick as a result of exposure to pollution from the tailings dump material.

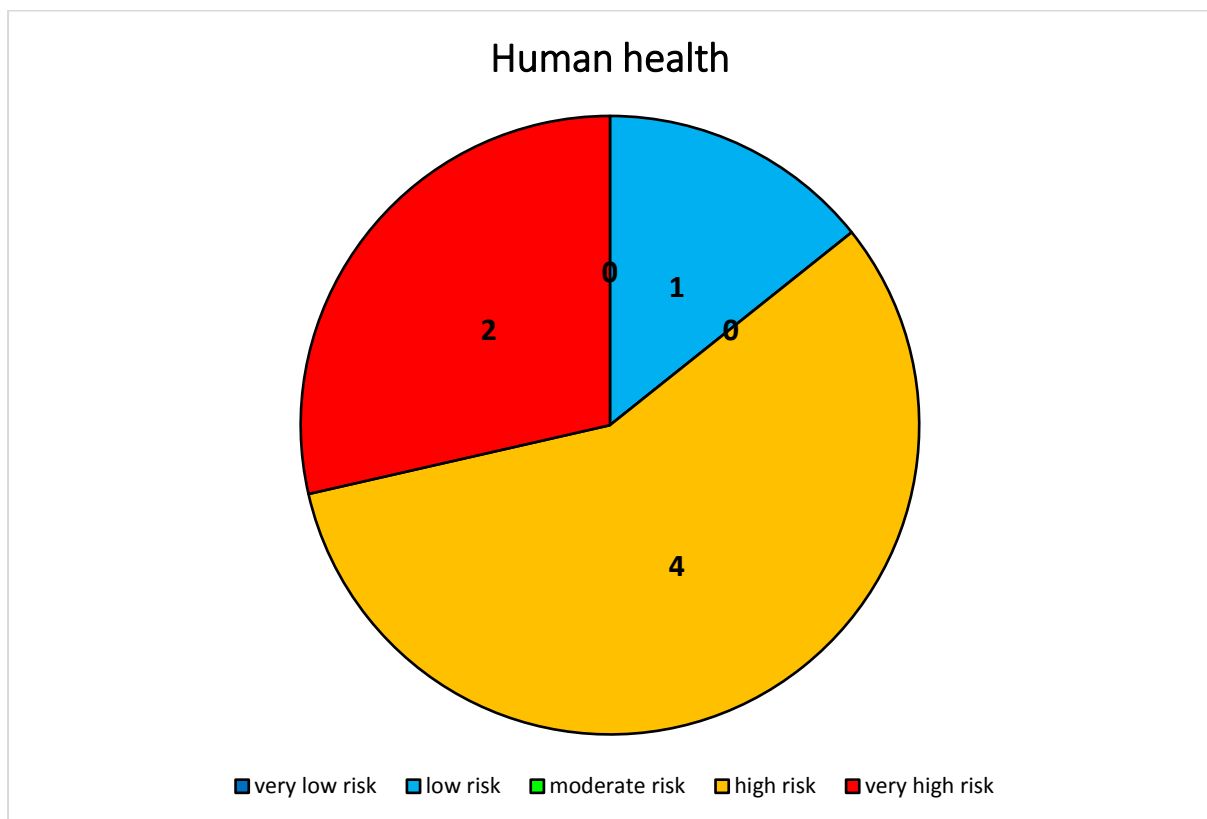


Figure 3- 11: Rating of human health risks (numbers on graph represent number of participants).

Also linked closely to human health is metal contamination. Based on the participants’ rating, 1 out of 7 rated metal contamination as a moderate risk, 2 rated it as a high risk, and 4 as a very high risk (Figure 3-12).

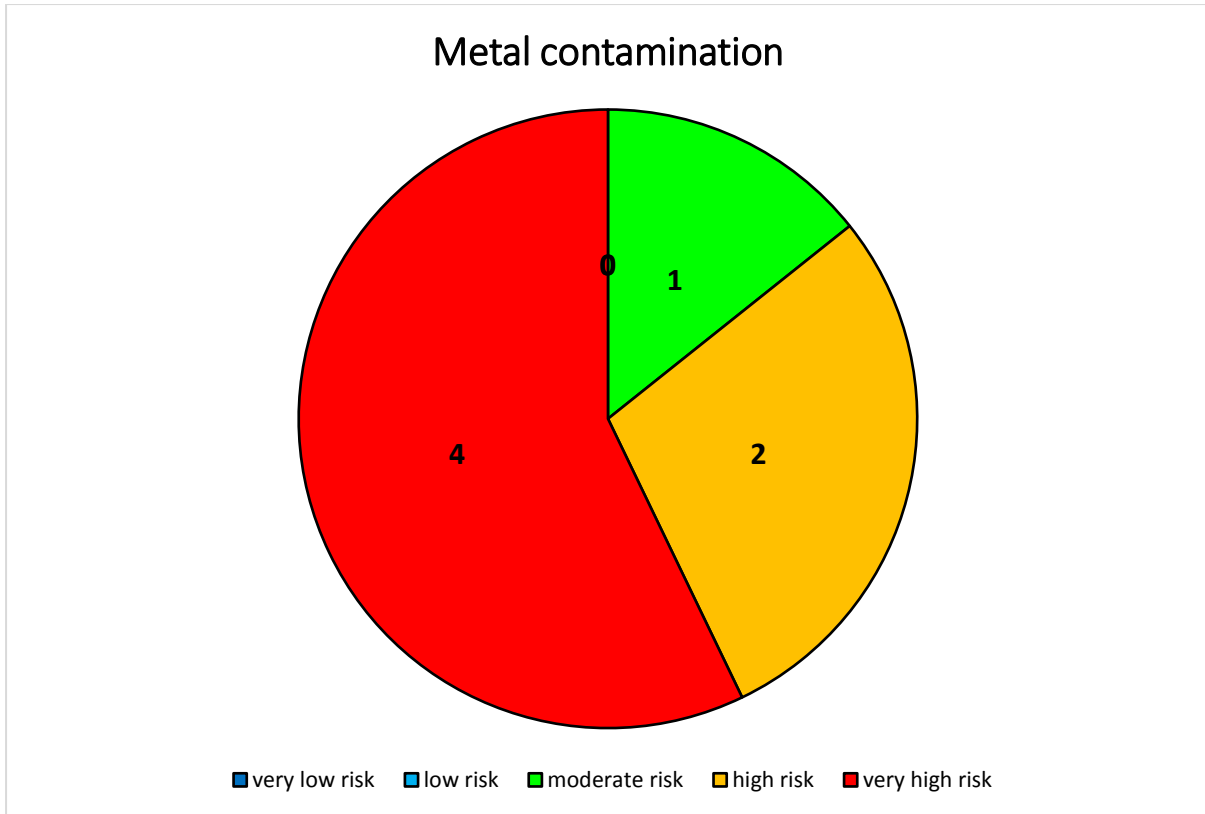


Figure 3- 12: Rating of metal contamination (numbers on graph represent number of participants).

According to experts and the community activist, the increased levels of aluminium (Al) and magnesium (Mg) were of concern, with participants stating that these have an effect on the health of the community members. Radiation due to uranium (U) and its decaying products was listed as another health risk associated with tailings dumps. *“Radiation from uranium and other decaying products is also associated with gold mine tailings dumps” – Participant 7.* Participant 7 stated that, due to the radiation of uranium, community members may be prone to sicknesses such as cancer and silicosis, which can be caused by the fine crystalline silica material that can be found in the gold tailings dump material.

One of the experts raised an issue of security and safety around the gold tailings dumps as the gold tailings dump is not fenced, making it easily accessible to the community members. Furthermore, there is no proper signage for people not to enter the site. The illegal miners (zama-zamas) also have easy access to the site. **Participant 6** stated that *“Security and safety around the dumps is of concern”*. With the reclamation of the old gold mine tailings dumps, physical safety of community members has also been mentioned by the environmental and human right activist. **Participant 5** stated that *“the municipalities place communities around the storage facilities, exposing the communities not just to dust, but physical risks of being exposed to mining.”*

(ii) Quality of life and livelihood

In general, all the participants agreed that the Princess tailings dump had a negative impact on the quality of life of the communities living in Davidsonville. *“There is always an impact on the community”* – **Participant 7**. **Participant 5** made mention that the community members are affected through the different pathways which impact the soil, crops, animals, and ultimately human beings. This participant also highlighted other areas in the Witwatersrand goldfields impacted on by gold tailings, namely Tudor Shaft in Kagiso, which is built on top of the gold tailings dump that is radioactive (also proven by the National Nuclear Regulator), and Snake Park in Soweto where community members have planted their crops near the dump for their consumption. Community members also indicated that moving away from the Davidsonville area was not an option due to their economic situation. *“No, I have not considered moving due to unemployment.”* – **Participant 1**; *“No, I cannot afford to move because of unemployment.”* – **Participant 3**. *“the economic situation does not allow me to do so (i.e. move).”* – **Participant 2**.

(iii) Crop productivity

The responses for crop productivity were quite diverse (Figure 3-13). Based on the participants' rating, 1 out of 7 rated crop productivity as a very low risk, 1 as a low risk, 2 rated it as a moderate risk, and 3 as a very high risk. Community members have reported that they do plant *“I do plant, and the plants grow.”* – **Participant 3**, however, there was limitation to certain crop species. *“Spinach grows holes and does not develop well”* – **Participant 1**. Participants mentioned that crop productivity is linked to soil fertility as the crop growth is dependent on the fertility of the soil. Since the soil is not fertile, compost has to be used in order to supplement the soil for the crops to grow appropriately. *“Soil fertility is very poor. People used to grow crops, but the quality is not good”* – **Participant 2**; *“I buy compost; the ones in the composite grow bigger than the ones in the soil. You get more quality in the compost”* – **Participant 3**. Also, of concern was dust from the tailings dump that settles on the crops. *“There is ingestion and inhalation of dust and deposition of dust on crops”* – **Participant 5**.

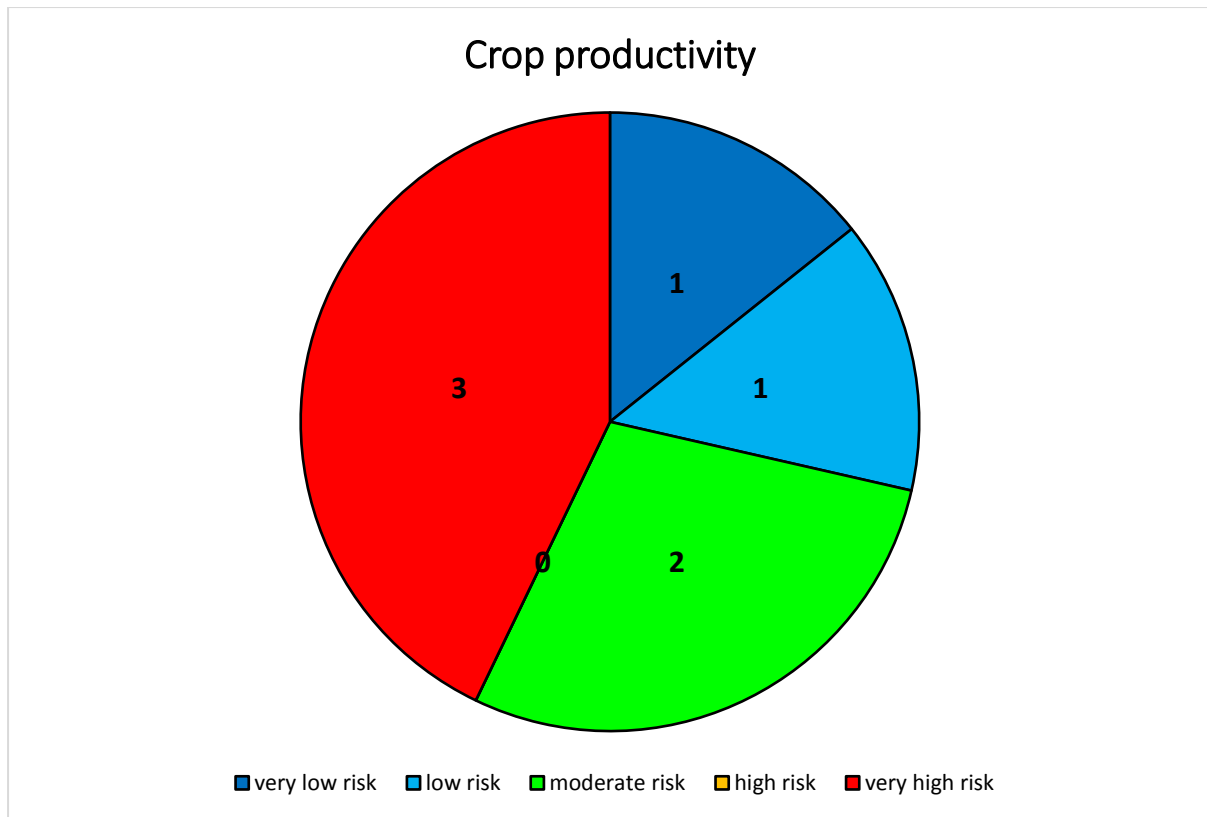


Figure 3- 13: Rating of crop productivity risks (numbers on graph represent number of participants).

(iv) Human activities (e.g. subsistence farming, recreational parks)

Based on the participants' rating, 1 out of 7 rated human livelihoods as a low risk, 2 rated it as a high risk, and 4 as a very high risk (Figure 3-14). All the community members (3) stated that the Princess tailings dump has impacted the recreational park that is situated adjacent to the dump (Figure 3-15). *"(The dump) also affects our park. Look around here, this is supposed to be a park but there are no children playing here"* – **Participant 3**; *"The kids can't play here; it is wet all-over. This is from the water that comes from the dump."* – **Participant 1**; *"Instead of green grass, there is brown grass"* – **Participant 2**. Animals and plants are also affected by the pollution caused by the tailings dumps. Although not referring to the study area, participant 5 gave an example about animals that were impacted by polluted mine waste. *"Study of the cows in the Wonderfonteinspruit catchment shows that cows were getting sick from drinking the water from the catchment that is polluted by mine waste."* – **Participant 5**.

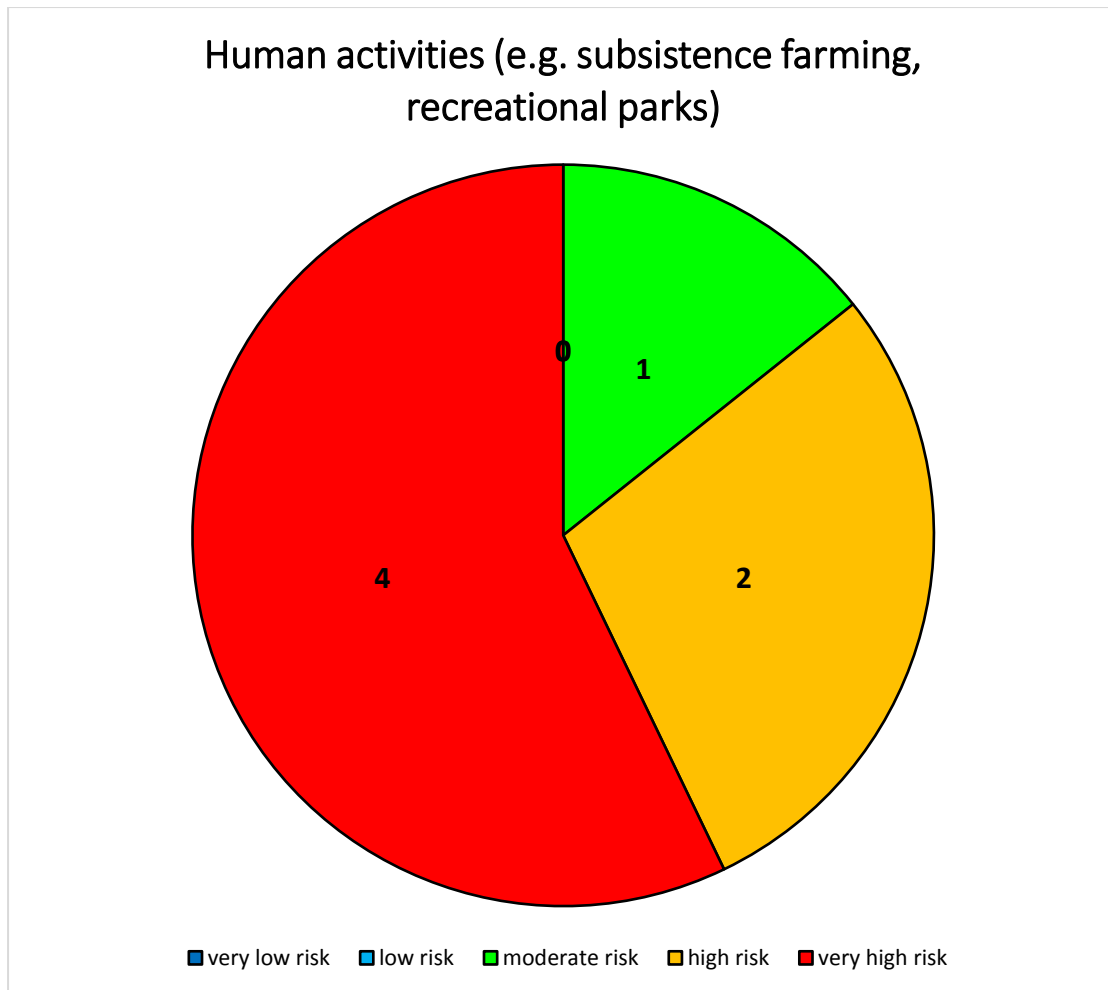


Figure 3- 14: Rating for human activities (numbers on graph represent number of participants).



Figure 3- 15: Water running through the park from the Princess tailings dump.

3.2.2. Communication and engagement

In order to establish the extent to which the current community concerns and expectations has been addressed by the responsible parties, this section addresses all the communication and engagement. This section aims to investigate the source of information with regards to the risks and impacts as identified in section 3.2.1, and where and to whom these incidents and concerns were reported.

3.2.2.1. Source of information regarding the risks and impacts

Participants were questioned about how they learned about the risks and impacts. The results are presented in table 3-3 below:

Table 3 - 2: Source of information

Source of information	No. of Participants
Community meetings with CSO	3
Media (Newspaper, TV, Radio)	3
Mining companies	4
Studies done and reports	4

From the responses that were given, the community members' source of information is mainly through the CSOs and media. *"I had learnt a lot and have met various informative organisations such as Bench Marks and when Witswest started mining people were informed."* – **Participant 1.** *"Information was gathered through NGOs."* – **Participant 3.**

The experts know of these impacts and risks through the mining companies and the various studies that they have conducted for the mining companies and government.

3.2.2.2. Reporting of incidents and concerns

The extent to which the conflicts and interests of the stakeholder, with regards to the impacts/risks that are associated with gold mine tailings dumps in Davidsonville, had been reported were interrogated. Participants were asked if their concerns and incidents have been reported, and to whom these concerns and incidents were reported. It should be noted that the concerns and incidents that were reported by the community members were mainly about the Princess tailings dump, while the subject experts and the civil society activist reported the concerns and incidents arising from gold mining and its waste in the Witwatersrand area in general. Results for the reporting

of incidents and concerns are tabled below (Table 3-4):

Table 3 - 3: Reporting of incidents and concerns

Recipients complains/reports	No. of Participants
Civil Society Organisations	3
Government Departments	4
Human Rights Commission	1
Media Departments	1
Mining Companies	3

According to the responses of the participants (Table 3-4), participants indicated that their concerns and incidents were reported to civil society organisations, various government departments including the local ward counsellor, and mining companies. These were reported through academic research, media reports, community meetings with civil society organisations, government, and mining companies. Memorandum of concerns and written expert reports accompanied by direct verbal conveyance were done. Of equal importance, the participants revealed that mining companies were informed of the main concerns through direct complaint channels and stakeholder engagement meetings. Reporting of defunct tailings concerns was also made public through media and peer-reviewed academic research. According to some of the participants, concerns have also been communicated to local government and community leadership during community meetings and protected formal protests.

The subject expert participants emphasized the fact that video graphics have been compiled, by both local and international media voicing concerns, of the impact of defunct gold tailings on water quality. A right of reply was also offered to many mining companies, yet nothing is being done to address the concerns. *“For 20 years these impacts and risks have been reported.”* – **Participant 5**. Community representatives agree with the comments by the subject expert participants and added the fact that lack of human, financial, and logistical resources are some of the factors that limit them from communicating their concerns effectively or challenge the responsible stakeholders in a legal forum such as the South African Human Rights Commission and the Constitutional Court.

3.2.3. Current and emergent responses

Even though all participants indicated that their concerns and incidents associated with the defunct tailings dumps have been reported, there is a perception that concerns and incidents have not

received adequate response, giving the impression that they are not taken seriously by the government and the mining companies. *"After the concerns were reported, there is no mitigation. Water is still seeping through the park, and there was no proper consultation with the community members. No plan to improve the situation."* – **Participant 1**. *"No, concerns were not attended to. The problem is the mining houses and government not taking them to the task."* – **Participant 3**. The community participants are of the view that the current active mining companies have no plans to address the impacts; instead, their focus is on how to extend the existing mines around the community. *"This is evident from new mining license applications by companies such as DRD Gold and Central Rand Gold around the Davidsonville area"* – **Participant 3**. Community participants (3) revealed that no senior government/mining company leader has ever attended community meetings, even though they are always invited.

Most of the incidents and concerns reported by subject experts and community activist were not exclusive to the tailings dump impacts in Davidsonville. In contrast to the above, experts and the community activist noted that, although there has been some response, this has largely been inadequate. *"Some have been dealt with but not all."* – **Participant 4**. *"Yes, they have been attended to by the mining companies, but not all of them."* – **Participant 6**. Expert participants, who partially agree that there have been some positive responses from key stakeholders, have argued that although there is still room for improvement when it comes to implementation of the various proposed solutions, there have been significant responses concerning legislative changes and approaches for mitigating the impacts associated with mining waste, especially the defunct gold tailings dumps. The subject expert participants 6 and 7 mentioned that several mine water treatment plants had been commissioned in the Witwatersrand area, but there is no budget for continuous operational expenses.

The subject experts, as well as the environmental and human right activist participant, explained that on regulatory issues, the government has made good strides to ensure compliance for any new mining license application. A good example is the water use licence (WUL) and compliance reports (CR) which are now made available to the public. The new WUL makes it compulsory for mining companies to make financial provision for the impacts (pumping and treatment of mine waste) throughout the life of the mine and post-closure. *"Yes, they have been attended to by the government. Water use licences and compliances are now publicly available."* – **Participant 5**. According to the subject expert participants, some of these interventions have already reduced impacts, while others could be expected to do so in the future. It was also mentioned that there is a lack of proper remediation for AMD. *"There is no proper acid mine drainage remediation"* –

Participant 6. Amendments in mine waste management (MWM) regulations, including the retrospective application of the “polluter pays principle” also have a potential to reduce the impact – **Participant 4 and 7.** However, all participants voiced concerns on enforcement of the regulations, stating that there are not enough public office bearers to conduct site visits, monitor the implementation of rehabilitation activities, and to assist community members with registering their concerns.

3.2.4. Participants’ aspirations and expectations

Participants were asked about the prospects with regards to impacts that are related to gold mine tailings dumps. There were three overarching future expectations with regards to the impacts that are associated with gold mine tailings. These are: (a) to rehabilitate, (b) to remove and; (c) to engage. The community members’ participants 1, 2 and 3’s prospects are that the gold tailings dump should be removed, and that the community members should be involved in the plans of removing the tailings dumps. *“Removal of the dump with community participation, no future mining (open or underground) as it creates a problem.”* – **Participant 1.**

Since the actual mining of gold gives rise to tailings dumps, experts (participants 4, 6 and 7) in the field of gold mining expressed that there should be mining with closure plans and that there should be proactivity in curbing the environmental pollution associated with gold mining and its waste while the gold mines are still operating. *“The future of mining is not great at all. There should be mining for closure, i.e. reprocessing of mine dumps then backfilling the mine when mine has been closed.”* – **Participant 4.** *“Pro-activity by mining companies to combat environmental pollution while still operating.”* – **Participant 5.** The existing gold tailings dumps should be vegetated so that there will be less air and water pollution. *“When vegetation methods are applied, there is less air and surface water pollution. The communities must not be relying on the surface water streams.”* – **Participant 6.**

There should be meaningful interaction between all stakeholders, that is, government, mining companies and civil society organisations. This will significantly increase the opportunity for the mining corporation to rehabilitate correctly. *“There should be benefit sharing with the community (investment into infrastructure, example roads, water etc.).”* – **Participant 4.** *“To have trust between the government, the mining companies and civil society organisations, the government should not be the ones to determine how the monetary contributions by the mines are allocated and where.”* – **Participant 7.**

Different stakeholders play a different role when it comes to the mitigation of the impacts that are associated with gold mine tailings dumps. Furthermore, there are expectations from various

stakeholders for the remediation of these impacts. This section aimed to gather the participants' expectations regarding stakeholder roles and actions in addressing current and future impacts and risks.

The following were the expectations for stakeholder roles:

(i) Roles of government

The functions of government according to the participants are tabled (Table 3-5) below:

Table 3 - 4: Perceived functions of government

Role	No. of Participants
Regulator and law enforcer	6
Conduct a study and mitigate/removal of dump	1

The majority of the participants expect the government to be the enforcer of the laws that are currently in place. The government is also expected to be the regulator and hold the mining houses accountable for the remediation of the environmental impacts that are associated with the waste that they produce during mining. Participants expressed that the government should not be the beneficiary of mining, but regulate the mining companies. *"Government should hold mining companies accountable/responsible."* – **Participant 3**; *"Government should be a regulator and not a beneficiary"* – **Participant 4**. Some of the participants expressed that not only should the government hold the mining companies liable for the impacts, but also the mine directors should be held personally responsible. *"Government – hold the mining companies' accountability for cleaning up. The directors of the mining companies should be held personally liable for the impacts."* – **Participant 6**

Furthermore, a community member stated the government should engage with the community members with regards to the rehabilitation methods that will be used in the mitigation of these environmental impacts. *"The role of government is to conduct the study to determine the contents of the mine dump, assist people to move the mining dump, come, and consult with people on how to mitigate."* – **Participant 1**.

One expert mentioned that the government's failure to regulate the gold mining companies has led to civil society groups being the re-enforcers. *"In the absence of the state to regulate, some activists*

have taken upon themselves to act as the re-enforcers which have made matters worse resulting in public mobilisation.” – Participant 7.

(ii) Roles of mining companies

The roles of mining companies according to the participants are tabled (Table 3-6) below:

Table 3 - 5: Perceived roles of mining companies

Role	No. of Participants
Remove the tailings dumps	2
Engage with civil society	2
Adhere to social and labour plans	1
Undertake remedial and clean-up plans after closure	2

One community member participant and an expert participant have stated that the role of the mining companies is to clean-up the waste (rehabilitate the tailings dump) that has resulted from their mining activities and take responsibility for the impacts that are associated with the gold tailings dumps. *“The role of the mining companies is to remove their waste and take responsibility. It is time for mining houses to take responsibility for their waste.” – Participant 1.* Also, two of the community participants called for the removal of the mine tailings dumps. *“Mining organisations should take the bulk of the responsibility to remove the dump and its radioactivity due to Uranium.” – Participant 3.*

Other participants expect the mining company to engage with the community and adhere to their social and labour plans. *“Mining companies to reach out to civil society organisations and engage them with all the stages of mining including post-mining; should be regulated.” – Participant 4.* *“Mining companies have to adhere to social and labour plans” – Participant 5.* The mining companies are expected to ensure that there are investments in the remedial action after the closure of the mines and that there is sustainable prevention of environmental pollution. *“Mining companies – ensure that they have a sustainable vegetative cover to prevent generation of dust.” – Participant 6.* *“Mining companies should invest in the clean-up after closure.” – Participant 7*

(iii) Roles of community and civil society organisations

The roles of mining community and civil society organisations according to the participants are tabled (Table 3-7) below:

Table 3 - 6: Perceived roles of civil society organisations and community

Role	No. of Participants
Provide evidence of impacts	2
Report incidences of pollution	2
Request feedback on remedial progress	2
Whistle-blowing	1
Determine the allocation of rehabilitation funds	1

Participants expected civil society and civil society organisations to report incidents of pollution due to gold tailings dumps. *“Civil society organisations provide evidence of impacts.”* – **Participant 3**. The civil society is expected to provide evidence of pollution due to gold tailings dumps to both government and the mining companies. *“Civil society organisations should report the incidents of pollution.”* – **Participant 5**. *“Civil society organisations will play an oversight role/ whistle blowing role.”* – **Participant 4**.

The civil society and civil society organisations should also play a role of holding mining companies and government accountable, and ensure that there are proper plans and progress on rehabilitation. *“Civil society organisations should demand public feedback on the progress on rehabilitation and demonstration of doing these things properly.”* – **Participant 6**. *“Civil society organisations and the communities should determine where the money for rehabilitation go to.”* – **Participant 7**.

3.3. Summary and synthesis

This chapter presented the results from the semi-structures interviews that were conducted with relevant stakeholders. It explored the stakeholders’ perceptions, concerns and experiences with regards to environmental and social impacts associated with waste generated by gold mining, specifically defunct gold tailings in Davidsonville, although the participants did broadly refer to gold tailings in the Witwatersrand area.

Princess tailings dump, which is the focus of this study, and which remains largely un-rehabilitated, was considered to pose a significant (very high) environmental impact, and be associated with major (high) social impacts. Dust from this tailings dump is a problem, particularly during the windy season. There is tailings dump seepage/run-off into the community park and it has been described as posing one of the hazards that limit the park usage by the community. The dump has been reported as taking up space (sterilising land) that could be used for other multiple purposes such as housing, agriculture,

and for construction of recreation facilities. Field investigation and participants' responses showed that due to limited space, houses have been built next to the tailings dump, with the 500 m required buffer zone not adhered to. The tailings dump material has been eroded to the streets and houses nearby. Notwithstanding the fact that no medical assessment has been conducted in the Davidsonville suburb, there is a perception and concern that the health of the residents of Davidsonville is negatively impacted by the environmental pollution due to the dump. Some of the community members/participants asserted that their life expectancy has decreased due to the defunct tailings dump.

With regard to communication and engagement, community members stated that they usually learn about the risks/impacts of the defunct gold tailings dump through community meetings, media, from mining companies, through studies done by NGOs, and through public reports such as academic dissertations. All of the participants stated that they routinely report the incidents of environmental and social impacts that are thought to be due to gold mining waste. These incidents were reported to different stakeholders such as civil society organisations, government departments, the Human Rights Commission, media, and mining companies. The challenge that the community faces when reporting the incidents of pollution by the gold mine tailings is that they are told to present prima facie evidence that is based on scientific measurements. This is not feasible due to limited expertise and resources.

Despite efforts to report incidents and communicate concerns, both with regards to the tailings dump in Davidsonville and the gold mining sector activities and its waste in the Witwatersrand area more broadly, the consensus amongst the participants was that responses by government and the mining sector were largely inadequate. The concerns and incidents that were reported by the community members were mainly about the Princess tailings dump, while the subject experts and the civil society activist reported the concerns and incidents arising from gold mining and its waste in the Witwatersrand area in general. Due to lack of human and financial resources, communities are limited in communicating their concerns effectively and/or legally challenging the stakeholders responsible for the pollution arising from the gold tailings dumps.

In general, participants expected the government to enforce the laws that are related to mining and waste, and regulate and hold mining companies accountable for remediation of environmental impacts associated with gold mine waste. In addition, the participants emphasised that mining companies should take responsibility for their environmental impacts and mitigation thereof, and adhere to social and labour plans. Subject matter experts advocated that civil society, together with the civil society organizations, should report incidents of pollution and hold government and mining

companies accountable through continuously voicing their concerns. With specific reference to expectations regarding the Princess tailings dump in Davidsonville, community members called for the dump to be removed, and for affected community members to be actively engaged in and consulted about remediation plans. The subject experts' future expectations were that there needs to be better mining closure plans and the rehabilitation of the tailings dump in order to curb pollution arising from gold mining and its waste in the Witwatersrand goldfields.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions and recommendations of this study. The chapter commences with an overview of the research problem and scope, followed by a summary of the key study findings. The chapter concludes with closing remarks and recommendations for further interventions and studies, established on the basis of the study results.

4.1. Introduction

This research study's main aim was to develop a better understanding of the facts, perceptions, concerns, and expectations associated with Witwatersrand gold mine tailings storage facilities, and how these are related. Therefore the study (i) reviewed and critically assessed the relevant literature concerning to the environmental impacts and the social impacts (that is, livelihoods, quality of life, and health of the society) of gold mining, processing, and defunct gold tailings; (ii) established the community's, civil society organisations' and subject experts' perceptions, experiences, and expectations about the socio-environmental impacts caused by defunct gold tailings in Davidsonville and; (iii) analysed the extent to which current community concerns and expectations have been addressed or perceived to have been addressed by responsible parties (for example, gold mining companies and/or the government). In order to fulfil the aim and achieve the objectives of the project, the study was conducted in two phases. Phase 1 was a desktop study which involved a detailed review of published academic literature, company reports, newspaper articles, gold mining magazines, and specialist reports, intending to meeting the first objective of this study. Specific emphasis was placed on the Central Rand goldfields area of the Witwatersrand. Phase 2 involved semi-structured interviews with representatives from community members, civil society organisations, and independent experts, with a view to meeting the second and third objectives of the project with focus placed on defunct Princess tailings dump in Davidsonville.

4.2. Key Findings: A Summary and Synthesis

4.2.1. Facts, concerns and experiences pertaining to the inter-related environmental and community impacts of gold tailings

In South Africa the gold mining legacy did not only bring socio-economic benefits, but it has also left over 215 un-rehabilitated tailings storage facilities. Although the environmental issues around mining

started to receive attention as early as 1980, South Africa had little legislation that clearly dealt with environmental protection from mining impacts prior to 1991. As a result, the current state of the tailings storage facilities remains un-rehabilitated, with some being ownerless. Due to scarcity of land near the city centre, there is often an encroachment of housing developments, both formal and informal, on the TSFs buffer zones, with a case of Tudor Shaft where people are residing on top of the gold tailings dump. The literature review of the study has shown that there is environmental pollution (air, water, and soil) due to gold tailings dumps in the Witwatersrand, resulting in adverse effects on health and quality of life of communities residing in their vicinity. These findings were found to be largely consistent with perceptions and concerns of the Davidsonville community, civil society organisations, and subject experts in Gauteng. The long-term impacts of this pollution are not only environmental, but causes a huge social burden on health and quality of livelihoods. Not only is dust a nuisance, particularly in the windy season, but the dust has been proven to contain crystalline silica and radionuclides. The long-term exposure to this dust can lead to skin problems and respiratory illnesses. There is higher exposure of ambient particulate matter (PM₁₀) in areas around tailings even at distances up to 2 km downwind from the tailings dumps. Acid mine drainage, on the other hand, increases metal load in watercourses and soils, ultimately affecting the ecosystems. Metal contamination results in the accumulation of metals in sediments, soils, and the environment at large, is toxic to plants, and poses a risk to animal and human health.

Semi structured-interviews results have shown that, coupled with the environmental and social impacts, the exclusion of community members in decision-making has resulted in conflicts between the government and communities, and also increased the distrust for mining companies. While a number of communities have suffered the adverse impacts of gold mining in the Central Rand, Davidsonville is one of the most prominent cases. A critical review of the literature showed the defunct Princess tailings dump in Davidsonville was never adequately rehabilitated. Both the literature and interviews indicated that the slopes of this tailings dump are unprotected, resulting in them being susceptible to soil and water erosion. There is continuous eroding of the tailings material due to seepage from the tailings dump. Also, during the rainy season, the tailings dump material is eroded. Erosion has the potential to increase the metal load of nearby water bodies such as the man-made wetland nearby, and affects the adjacent community of Davidsonville. When it is windy, the dust from the tailings dump causes air pollution. One of the environmental hazards identified is the seepage of acidic waters from the tailings into recreational areas. For example, the seepage of acidic waters from the tailings usually floods Manuel Street Park and residents' yards, thus leaving stagnant pools during the wet season. It has been shown in this study and cited in a number of previous studies that demonstrated that decanting waters from the tailings are characterised by low pH, high

concentrations of dissolved metals, and high levels of SO_4^{2-} ions. The soil and water in Davidsonville are contaminated with metals with the soil pH reaching 3.04 and the water pH of 3.24. The community of Davidsonville has associated their health problems with the defunct Princess tailings dump. This has led to conflicts between community, government, and mining companies. This was evident from both the literature survey and the interview responses.

The tailings dump prevents the community of Davidsonville from utilising the land for social and economic activities, with houses built less than 50 m from the tailing dump. It emerged from the semi-structured interviews that pollution around the defunct gold tailings affects the livelihoods of the community members negatively. The community members cannot utilise recreational areas such as the public Manuel Street park, as it is often flooded by water from the tailings dump. Therefore, there is a need for remediation and rehabilitation plans in order to improve the public open space of the people of Davidsonville and places of a similar nature. The dust has been described as a nuisance and the source for the respiratory illnesses. Literature shows that the social concerns have been voiced in various legal courts, and much of it was due to lack of engagement between the different stakeholders and lack of ownership from those who are deemed to be responsible for the long-term pollution. To date, there has been no major repercussions for these legacies of environmental pollution and social concerns.

4.2.2. Responses and expectations

Responses that were gathered during interviews show that the concerns and incidents of pollution by defunct tailings dumps have been reported to the different stakeholders. The incidents have been reported to the government departments, mining companies, civil society organisations and, media departments. Even though all participants indicated that their concerns and incidents associated with the defunct tailings dumps have been reported, there is a perception that concerns and incidents have not received adequate response, giving the impression that they are not taken seriously, particularly by the government and the mining companies. Room for improvement exists, particularly in the implementation of various proposed solutions to the concerns, however, there have been significant responses concerning legislative changes and approaches for mitigating the impacts associated with mining waste, especially the defunct gold tailings. An example is the amendments of the water use licence and compliance reports as well as the waste management regulations. While there is regulations and legislature to deal with environmental pollution, there were concerns on enforcement of the regulations, as there are insufficient public office bearers to do site visits, monitor the implementation of rehabilitation activities, and to assist community members with registering their concerns. The literature shows that there have been some mitigation actions from the mining

companies such, as vegetation of gold tailings dumps to curb pollution and reclamation of these tailings.

There were three overarching future expectations with regards to the impacts that are associated with gold mine tailings, these are: (a) to rehabilitate, (b) to remove and; (c) to engage. Public participation is one of the crucial factors of sustainable development. There seems to be a breakdown in communication between key stakeholders such as the community, mining companies, the government, and non-profit organisations. Community members feel that decisions taken through existing bureaucratic and formal processes often do not include their main concerns. While all interviewed participants agree that appropriate extraction of natural resources such as gold mining depends on the strength of the country's guidelines, implementation of existing legislation is lacking. For example, South Africa has many laws relating to the management of mineral resources, environment, and biodiversity, but most are not implemented. Difficulty in implementing laws may stem from conflicting mandates among government agencies such as the role of the Department of Mineral Resources versus the Department of Environmental affairs. Community representatives, civil society organisations, and subject experts expressed that an essential component of sound social and environmental laws is the ability to hold polluters accountable. This may be accomplished through a requirement to declare a reclamation account, which should be held until the company has satisfactorily complied with government regulations for closure and remediation of a mine site. However, this is not currently enforced, although it is registered as part of the legislation. Addressing socio-environmental impacts caused by defunct gold tailings problems and injustices requires coordinated activities and joint programmes between all stakeholders. Although government and mining companies have recognised the vital role that non-profit organisations and subject experts (academia) could play in achieving sustainable development and ensuring ongoing advocacy, few attempts have been made to work with these organisations, academia, and communities. Overall, it appears that community environmental problems and their socio-economic problems are a low priority and do not receive the attention and action they deserve from the government and mining companies. These general perceptions from the interviewees are that better communication channels and open forum engagements can help to address the relationships value chain between the community, mining companies, the government, non-profit organisations, and subject experts.

Recent concerns regarding the potential conflicts associated with defunct gold tailings have prompted the Davidsonville community to pass non-binding referendums banning new mining development initiatives. Although some of the concerns have been partially addressed, the Davidsonville community feel that a lot still need to be done and both the government and mining companies are not prioritising

their interests. Communities often turn to non-profit organisations to expose their social and environmental problems. However, non-profit organisations are not always in a position to provide the resources needed to address the issues. It is vital to note that non-profit organisations often have constraints that include a lack of funding, inadequate capacity, slow or no follow-up, and lack of expertise which makes it very difficult to be efficient. Due to increased volatility of the situation, key stakeholders may find it difficult to identify genuine community representatives as a number of civil society organisations have now been established with different mandates. Both the literature and interviews indicated that there is a lack of scientific evidence on the concerns raised by community members, and the direct impact of pollution to human health and quality of livelihood has not been directly established. Where informal litigation was employed as a means to redress social and environmental concerns, lack of sufficient evidence led to a failure to resolve the issues. Much of the evidence presented by civil society organisation revolves around the proximity of the defunct tailings dumps relative to the residential areas and semi-quantitative dust fallout estimates. From the observed evidence gathered through reports and studies in the literature survey, it can be concluded that defunct gold tailings are most likely to result in long-term health impacts to the Davidsonville community. However, this needs to be assessed through detailed epidemiological studies and quantitative measurements of pollution.

4.3. Concluding remarks and recommendations

Literature survey and semi-structured interviews revealed that defunct gold mine tailings dumps are a source of environmental pollution. According to the findings of this study, the polluted environments has not been rehabilitated, thus resulting in community members attributing poor health to environmental pollution from the gold tailings dumps. However, despite these claims, there have not been any epidemiological studies to prove that the mine dumps pose a human health risk or to establish exposure pathways. It is therefore recommended that a research study be conducted to:

Assess the potential health risks of irrigating vegetable gardens using contaminated surface and underground water in the Davidsonville area and adjacent suburbs.

Government and mining companies have come up with interventions to combat the pollution and social impacts arising from defunct tailings dump. The interventions by mining companies include the reclamation of these tailings dumps for residual gold, rehabilitation of defunct tailings, backfilling of mine shafts with the tailing material, and the establishment of super dumps. Despite these interventions, conflicts between mining companies and communities continue to occur. This study has also established that the role of government is not clear, as it is both the regulator and benefactor

of mining. As a result, civil society organisations do not trust the government to hold the mining companies accountable for environmental pollution. This has then given rise to activism by non-governmental organisations aiming to take the gold mines and government to task and demand that both parties take accountability for the damage caused. It is thus recommended that:

A framework document be created with the aim of improving engagement between the different stakeholders (community, government, and mining companies). This will ensure that the residents have the right to correct information and can raise concerns to the relevant stakeholders. In turn, government and mining companies will benefit from proactive engagements, thus allowing them to allocate necessary requirements for removal or treatment of defunct gold tailings.

Current mitigation approaches, including rehabilitation and the reprocessing and replacement of tailings, do not result in the total removal of risk through reuse or repurposing, an expectation that emerged from interviews with community members. In line with opportunities identified in a study by Sibanda and Broadhurst (2018), it is thus recommended that:

The gold tailings dumps be re-purposed/reused after it has been pre-treated of the impurities, such that it will not cause any environmental and social impacts. It is, furthermore, recommended that this be done in partnership with communities and local businesses in a way that creates shared value/economic benefit.

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APPENDICES

APPENDIX A

HEALTH IMPACTS CAUSED BY METALS ON HUMANS

a. Lead

Lead is abundant and occurs as metallic lead, inorganic ions or salts (Harrison, 2001). It is a toxicologically relevant element that has been brought in huge amounts and distributed to the environment by humans. This is despite lead having low geochemical mobility (Morais et al., 2012). Lead has no vital function in a human body, but it can have a toxic effect irrespective of the exposure pathway. One of the major sources of lead exposure is food (that is, lead-contaminated vegetation or animal foods) and other sources are through the air, soil and drinking water. Contaminated soils pose a risk through direct ingestion, uptake in vegetable gardens, or trailing into households. Soils that are contaminated contain lead concentrations that are less than 50 ppm. The Environmental Protection Agency's standard for lead in bare soil in play areas is 400 ppm by weight (ATSDR, 2012). In water, the maximum contaminant goal is zero, and the maximum is 10 µg/L (WHO, 2001; ATSDR, 2012).

When inhaled, about 20 to 50 % inorganic lead is absorbed and when ingested, about 5 to 15 % of inorganic lead is absorbed (Morais et al., 2012). On the other hand, organic lead is absorbed readily when ingested and about 80 % is absorbed when inhaled. Lead is primarily distributed among blood, soft tissue, and mineralising tissue once it has entered the bloodstream (Ming-Ho, 2005). Children are particularly sensitive because of their developing nervous system that is associated with more rapid growth rate and metabolism (ATSDR, 2007; Castro-González and Méndez-Armenta, 2008). When exposed to lead, children can suffer from reduced physical and mental growth, and may have a lower intelligence quotient (IQ). During pregnancy, lead can be passed on to the child from the mother and when breastfeeding (WHO, 2011). Lead is neurotoxic, which means it destroys brain and nerve cells and can cause irreversible neurological damage (ATSDR, 2012). Exposure to lead has also been associated with attention deficit hyperactivity disorder and antisocial behaviour. Lead has been determined to be a probable human carcinogen by the Environmental Protection Agency.

b. Cadmium

Cadmium occurs naturally in the environment. It is found in the air, soils, sediments and in unpolluted seawater (Morais et al., 2012). Recently the use of cadmium has increased due to increasing technological use, hence, consideration has been given to cadmium as a possible contaminant.

Although most countries have strict controls for the emissions of metals, cadmium is discharged to the air by mines, metal smelters and industries using cadmium compounds for alloys, batteries, pigments and in plastics (Harrison, 2001). One of the largest sources of cadmium exposure in humans is tobacco-smoking (Ming-Ho, 2005). Other than smoking, food products account for most of the human exposure to cadmium (Morais et al., 2012). This is due to the fact that the cadmium ions are readily absorbed by plants and equally distributed over the plant. As a result, people are exposed to cadmium when consuming plant-based and animal-based foods. As recommended by the World Health Organisation (2013), the threshold for cadmium in soils is 0.007 ppm. The EPA maximum contaminant level for cadmium in drinking water is 5 µg/L, whereas the WHO adopted the provisional guideline of 3 µg/L (WHO, 2001).

Cadmium has the ability to accumulate in human bodies, affecting the organs negatively. Organs that can be affected and/or damaged are liver, kidneys, lungs, bones, placenta, brain and central nervous system (Castro-Gonzalez and Mendez-Armenta, 2008). Other damage includes reproductive, and development toxicity, hepatic, haematological, and immunological effects (ATSDR, 2008). Cadmium can be passed from mothers to children through breastfeeding, and during pregnancy can cause negative effects on behaviour and learning, as well as abnormal foetal metabolism, low foetal weight, and skeletal deformations.

c. Mercury

Found in air, water, and soil, mercury is a naturally occurring element. However, coal combustion and gold mining are a source of mercury contamination (Oosthuizen et al., 2010). Approximately 45 % of the total mercury emissions in Africa are accounted for by gold production from large and small-scale mining (Dabrowski et al., 2008). Mercury is used to bind gold from the ore and then it is burned to recover the gold. This is usually done in artisanal mining. Mercury is toxic even at low concentrations, in particular, methylmercury (the organic form of mercury), and it can accumulate in fish. Mercury in the human body is associated with personality changes, deafness, changes in vision, loss of muscle coordination or tremors, loss of sensation, and difficulties with memory. Mercury can be passed from pregnant mothers to unborn children, and also to babies, through breastfeeding. Children are most sensitive to harmful effects of mercury because of their developing nervous systems. Fetuses and children are especially sensitive to the harmful effects of mercury. The current standards for mercury in drinking water were set by EPA and WHO at the very low levels of 2 µg/L and 1 µg/L, respectively (WHO, 2001).

d. Arsenic

Arsenic is a metalloid that is rarely found as a free element in the natural environment. It is commonly found as a component of sulphidic ores in which it occurs as metal arsenides (Morais et al., 2012).

Arsenic is associated with geological sources, but it is quite widely distributed in natural waters. However, in some localities, anthropogenic inputs, such as the use of arsenical insecticides and the combustion of fossil fuels, can be very significant extra sources of arsenic. In natural waters, arsenic occurs in oxidation states III and V, a form of arsenous acid (H_3AsO_3) and its salts, and arsenic acid (H_3AsO_5) and its salts, respectively (Sawyer et al., 2003). Although arsenic occurs naturally, human activities, especially mining and the burning of coal, have increased the mobilisation of mercury into the environment, resulting in elevated amounts in the atmosphere, soils, fresh waters, and oceans.

The toxic effects of arsenic depend on oxidation state and chemical species, with inorganic arsenic known to be carcinogenic and related mainly to lung, kidney, bladder, and skin disorders (Morais et al., 2012; ATSDR, 2003). The toxicity of arsenic in its inorganic form has been known for decades in the following forms: acute toxicity, subchronic toxicity, genetic toxicity, developmental and reproductive toxicity, immunotoxicity, biochemical and cellular toxicity, and chronic toxicity (Chakraborti et al., 2004; Sakurai et al., 2004; Schwarzenegger et al., 2004). One of the primary sources of inorganic arsenic exposure is drinking water (National Research Council, 2001). Chronic arsenicosis and arsenic toxicity is of a worrying magnitude and is a major environmental health disaster (Bhattacharya et al., 2007; Chakraborti et al., 2004; Kapaj et al., 2006). Carcinogenic and noncarcinogenic health effects are known to be caused by chronic arsenic ingestion of drinking water. Chronic arsenic ingestion from drinking water has been found to have carcinogenic and noncarcinogenic health effects in humans (ATSDR, 2003; Morais et al., 2012). The maximum contaminant limit of arsenic in drinking water is 10 $\mu\text{g/L}$ as per WHO guidelines.

e. Uranium

Uranium is a naturally occurring metal which is found in various chemical forms. Through the dietary intakes of water, food, and air, the human body contains approximately 90 μg of uranium with about 66 % found in the skeleton, 16 % in the liver, 8 % in the kidneys and 10 % in other tissues (WHO, 2011). Natural uranium consists of a mixture of three radioactive isotopes, that is, uranium-238 (U-238), uranium-235 (U-235) and uranium-234 (U-234). Uranium like all the radioactive isotopes decays. Depleted uranium has both chemical and radiological toxicity, with the two important target organs being the kidneys and the lungs. The physical and chemical nature as well as the level and duration of exposure of the depleted uranium to which an individual is exposed determines the health impacts. Long-term studies of workers exposed to uranium have reported some impairment of kidney function depending on the level of exposure. Insoluble inhaled uranium particles of 1-10 μm in size, tend to be retained in the lung which may result in irradiation damage of the lung and

even lung cancer should its presence results in a high enough radiation dose over a long period (WHO, 2011).

f. Chromium

Chromium (Cr) is naturally occurring and is widely dispersed in the Earth's crust. Human exposure to chromium can be through breathing, eating, or drinking and through skin contact with chromium or chromium compounds. In air and water, the levels of Cr are generally low, however contaminated water may contain the dangerous Cr(IV). The major intake of Cr is through food. Since Cr(III) is essential for humans and is poorly absorbed by any route, the toxicity of chromium is mostly attributable to the Cr(VI) form (ATSDR, 2011). Cr(IV) may be absorbed by the lung and gastrointestinal tract, and to some degree by intact skin. Occupational exposures often include mixed exposure to both Cr(III) and Cr(VI). Human occupational experience shows that, chromium compounds when inhaled are respiratory tract irritants, resulting in airway irritation, airway obstruction, and lung, nasal, or sinus cancer. Following inhalation of Cr dust, the pulmonary irritant effects may include asthma, chronic bronchitis, chronic irritation, chronic pharyngitis, chronic rhinitis, and congestion (ATSDR, 2011).

g. Nickel

Widely distributed in the Earth's crust, nickel is a transition element. Nickel (Ni) occurs from both natural sources and anthropogenic activity. Environmental pollution from nickel may arise from industry activities, the use of liquid and solid fuels, as well as municipal and industrial wastes. Due to contact with Ni a wide range of side effects on human health may occur. Effects such as allergy, , cardiovascular and kidney diseases, lung fibrosis, lung, and nasal cancer. The mitochondrial dysfunctions and oxidative stress are thought to have a primary and crucial role in the toxicity of Ni even though the molecular mechanisms of nickel-induced toxicity are not yet clear (Genchi et al., 2020).

APPENDIX B

ETHICS CLEARANCE

From: reply-to+38fea2ff-675b-40ad-a735-a9cc708cf9e3@email.submittable.com on behalf of Faculty of Engineering and the Built Environment <reply-to+38fea2ff-675b-40ad-a735-a9cc708cf9e3@email.submittable.com>
Sent: Thursday, October 3, 2019 10:26 AM
To: phumzyt3@gmail.com
Subject: EBE - Ethics application APPROVED

Submittable 

Dear Phumzile Cynthia Nwaila,


Thank you for your submission.

Upon review, your application has been accepted with the following comments made by the reviewers to be taken into consideration:

Please find signed ethics form attached.

All the best!
Regards

 [Reply](#) [View Submission](#)

 There are files available for download via Submittable.

 [Download in Submittable](#)

APPENDIX C

INFORMED CONSENT FORM

The impacts and conflicts associated with waste generated by gold mining in South Africa – a case study of Central Rand goldfield.

Good day, my name is Phumzile Nwaila and I am currently enrolled as an MPhil student at the University of Cape Town. I'm currently doing my research project which focuses on the impacts and conflicts associated with waste generated by gold mining in South Africa – a case study of Central Rand goldfield. The aim of the research project is to determine the impacts and conflicts associated with gold mining sector in South Africa, using Davidsonville, Meadowlands and Riverlea in Central Rand goldfields (Johannesburg) as a case study. I hereby wish to invite you to participate in my research project.

Based on literature information it has emerged that pollution by gold mining and its waste has a negative impact on the health and livelihood of communities residing in and around the mining operations and mine tailings dumps. Again, it has been established that there are conflicts that exists between the mining companies, government and civil society regarding gold mining and mine waste. The objectives of the study is to: (a) identifying sources and incidents of environmental pollution and the impacts that this has on the community of Davidsonville, and the actions taken in order to address the issues, (b) evaluating the community's current perceptions and knowledge, conflicts and legal rights regarding environmental emissions, (c) analysing the extent to which the current community concerns are being addressed by the mining companies and/or government, and whether scientific facts provide sustenance for concerns; and (d) identifying the shortcomings with regards to (b), and making recommendations accordingly.

Your participation is voluntary and the choice to participate is yours alone. Should you choose not to participate, there will be no negative consequences. Should you choose to participate, but wish to withdraw at any time, you will be free to do so without negative consequences. Should you choose to participate on the interview the following procedure will be followed: Firstly, the informed consent form will be sent together with the abstract and interview schedule via email. I will then contact you to set up meeting to annotate and record the responses in a face-to-face interview.

This project forms part of the on-going Water Resource Commission (WRC) project. The information that you supply will be compiled with that from other industry experts, selected academics and communities, and this information will be used to derive the impacts and conflicts that exist in the

selected study area and ultimately to derive resource efficient and socially responsible approaches for the integrated management of mine waste by understanding the opportunities, enablers, barriers and risks involved. Information will be available upon your request.

Thank you very much for your assistance.

Yours Sincerely,

Phumzile Nwaila

MPhil student

Minerals to Metals Initiative | Department of Chemical Engineering | University of Cape Town

I, the undersigned, confirm that (please tick as appropriate):

1.	I have understood the objectives of the project, as explained by the researcher.	
2.	I have been given the opportunity to ask questions about the project and my participation.	
3.	I voluntarily agree to participate in the project.	
4.	The procedures regarding confidentiality have been clearly explained to me.	
5.	I agree to the audio recording of this interview.	
6.	I understand that other researchers will have access to this data only if they agree to preserve the confidentiality of the data and if they agreed to the terms I have specified in the form.	

Please specify the terms based on point 6 above:

Participant:

Name:

Organisation:

Role:

Signature:

Date:

Researcher:

Name:

Signature:

Date:

APPENDIX D

COMMUNITY INTERVIEW SCHEDULE

Survey Questionnaire- Section A

As part of the study, a list of variables (risks/impacts) has been compiled to assess the perceptions and understanding that exist due to gold tailings dumps intertwined with residential areas. Based on your observation, experience and practice please rate the extent of impact/risk associated with gold tailings dump as per table below. Rate the risk/impacts from 1-5 with 5 being a very high risk/impact and 1 being a very low risk/impact. Place a cross under the relevant response.

Risk/Impact	1	2	3	4	5
Air quality					
Water quality					
Soil fertility					
Crop production					
Health of natural ecosystems					
Human health					
Land loss/occupation					
Tailings dump overflow/leakage					
Tailings dump material erosion					
Metal contamination					
Human activities (e.g. subsistence farming, recreational parks)					

Interview Questionnaire - Section B

Based on your responses in Section A, please answer the following questions:

1. What is your current understanding of the following risks/impacts in relation to gold tailings dump?
 - a. Air quality
 - b. Water quality
 - c. Soil fertility
 - d. Crop production
 - e. Health of natural ecosystems
 - f. Human health
 - g. Land loss/occupation
 - h. Tailings dump overflow/leakage
 - i. Tailings dump material erosion
 - j. Metal contamination
 - k. Human activities (e.g. subsistence farming, recreational parks)
2. Are there any other risks/impacts relating to gold tailings dumps that you are aware of? If yes, please provide additional details.
3. Would you say these risks/impacts affect you and/or the community at large? If yes, please give details on the effects and specific incidents of which you are aware of.
4. Have the concerns outlined in Q1-3 above been reported? If yes, how were these concerns reported and to whom? Please give details on your response.

Note: This question is designed to interrogate the current awareness and information on interventions by industry, government or any other organisations to monitor and/or mitigate the impacts associated with the tailings, as well as the level and extent of feedback received on reported concerns.
5. Have these concerns been attended to or are there any plans in place for prevention, mitigation and/or monitoring that you know of? Please give details on your response.
6. Have you ever considered moving away because you were concerned about the state of the environment and/or your health?

7. What roles do you think that government, mining organisations and civil society should be playing in addressing the risks/impacts and liabilities associated with metal contamination by gold tailings dump?
8. What are your future prospects regarding pollution by gold tailings dump and the associated risks/impacts in the community(s)?
9. How did you learn about the risks/impacts associated with metal contamination by gold tailings dump?

EXPERT INTERVIEW SCHEDULE

Survey Questionnaire- Section A

As part of the study, a list of variables (risks/impacts) has been compiled to assess the perceptions and understanding that exist due to gold tailings dumps intertwined with residential areas. Based on your observation, experience and practice please rate the extent of impact/risk associated with gold tailings dump as per table below. Rate the risk/impacts from 1-5 with 5 being a very high risk/impact and 1 being a very low risk/impact. Place a cross under the relevant response.

Risk/Impact	1	2	3	4	5
Air quality					
Water quality					
Soil fertility					
Crop production					
Health of natural ecosystems					
Human health					
Land loss/occupation					
Tailings dump overflow/leakage					
Tailings dump material erosion					
Metal contamination					
Human activities (e.g. subsistence farming, recreational parks)					

Interview Questionnaire - Section B

Based on your responses in Section A, please answer the following questions:

1. What is your current understanding of the following risks/impacts in relation to gold tailings dump?
 - l. Air quality
 - m. Water quality
 - n. Soil fertility
 - o. Crop production
 - p. Health of natural ecosystems
 - q. Human health
 - r. Land loss/occupation
 - s. Tailings dump overflow/leakage
 - t. Tailings dump material erosion
 - u. Metal contamination
 - v. Human activities (e.g. subsistence farming, recreational parks)
2. Are there any other risks/impacts relating to gold tailings dumps that you are aware of? If yes, please provide additional details.
3. Would you say these risks/impacts affect the community at large? If yes, please give details on the effects and specific incidents of which you are aware of.
4. Have the concerns outlined in Q1-3 above been reported? If yes, how were these concerns reported and to whom? Please give details on your response.
5. Have these concerns been attended to or are you aware of any plans in place to do so? Please give details on your response.

Note: This question is designed to interrogate the current awareness and information on interventions by industry, government or any other organisations to monitor and/or mitigate the impacts associated with the tailings, as well as the level and extent of feedback received on reported concerns.
6. What roles and actions do you think that government, mining organisations and civil society should be playing in addressing the impacts and liabilities associated gold tailings dump impacts?

7. What are your thoughts regarding gold tailings dump management and the associated risks/impacts in the community(s)?